EVALUATION OF PROPAGATION SENSITIVITY OF COMMERCIAL EXPLOSIVES

FINAL REPORT

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SUMMARY

An investigation was made of the factors that can affect small diameter Slurry, Water Gel, and Emulsion propagation sensitivity including confinement, charge diameter, explosive composition, temperature, material to be cross-propagated, and degree of coupling of the charge to the borehole wall. The "Up and Down" experimental method was chosen to determine the 50 percent initiation point for the explosives at each charge diameter under all test conditions. Both donor and acceptor charges were instrumented to indicate initiation or failure and to determine the donor velocity of detonation.

The results obtained allowed scaling laws to be derived relating charge diameter to air, sand and water gap lengths at 5, 50 and 95 percent cross-propagation probability for Slurry/Water Gel and Emulsion type products. Although tests concentrated on small charge diameters, the scaling laws derived may also be applicable to larger diameters. Several possible applications of the scaling laws are outlined in the report.

The small diameter Emulsion products were shown to have very poor cross-propagation sensitivity for all test conditions. It is apparent that the method used in loading small diameter cartridged products can cause problems with maintaining a steady state detonation.

The cross-propagated gap distances for the Slurry/ Water Gel type products were found to be larger than anticipated. These products at a 2 inch charge diameter will cross-propagate an air gap distance of 5 feet 5% of the time and 3.5 feet 95% of the time. The propagation sensitivity of the Water Gel products, however, varied more than the Slurry or Emulsion products. At 5°C, the 1 inch diameter Water Gel product failed when fully coupled and when it was decoupled in a 1 3/4 inch diameter hole.

SOMMAIRE

Une étude a été faite sur les facteurs qui peuvent influencer la sensibilité à la propagation de produits de type "Slurry", "Water Gel" et "Emulsion" lorsque utilisés en charges de faibles diamètres. Ces facteurs sont le confinement, le diamètre de charge, la composition de l'explosif, la température, le materiel au travers duquel l'explosion doit se propager et la différence entre le diamètre de la charge et celui du trou. On a choisi la méthode l'expérimentation "Up and Down" pour déterminer le point l'initiation à 50% des explosifs pour chaque diamètre de charge et dans toutes les conditions de test. Le donneur et l'accepteur ont été dotés l'instruments permettant l'indiquer l'initiation ou l'échec et de déterminer la vélocité de détonation.

Les résultats obtenus ont permi de développer des lois de correspondance, en fonction du diamètre de la charge par rapport à l'épaisseur d'air, de sable et d'eau, à des probabilites de propagation de 5, 50 et 95 pour-cent pour les produits de type "Slurry", "Water Gel" et "Emulsion". Même si les essais ont porté principalement sur des charges de faibles diamètres, les lois de correspondance ont été jugées applicables à de plus grands diamètres de charge. Plusieurs applications des lois de correspondance sont exposées dans le rapport.

On a démontré que lorsque les diamètres de charge sont faibles, les produits de type "Emulsion" avaient une trés pauvre sensibilité à la propagation dans l'ensemble des conditions de test. Il est manifeste que des problèmes de détonation continue se présenteraient lors d'utilisation de produits en cartouches de petits diamètres.

Les distances de propagation pour les produits de type "Slurry" et "Water Gel" se sont révélées plus grandes que prévues. Ces produits en charges de 2 pouces de diamètre vont se propager à travers un espace d'air de 5 pieds 5% du temps et 3.5 pieds 95% du temps. La sensibilité à la propagation a une plus grande variabilité pour les produits de type "Water Gel" que pour les produits de type "Slurry" ou "Emulsion". Le produit "Water Gel" de 1 pouce de diamètre a échoué lorsque le diamètre du trou était aussi de 1 pouce et que la température était de 5°C, il a aussi échoué lorsque le diamètre du trou a été augmenté à 1.75 pouce.

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EVALUATION OF PROPAGATION SENSITIVITY OF COMMERCIAL EXPLOSIVES

1.0 INTRODUCTION

One of the properties of a commercial explosive that is of great interest is the ability of one cartridge to propagate to an adjacent cartridge in a borehole if these cartridges are not in direct contact but are separated by a gap of either air, water, sand or some other material. This study characterizes those factors that can affect propagation sensitivity. They are confinement, charge diameter, explosive composition, temperature, material between cartridges, and degree of coupling of the charge to the borehole wall.

Initially, the air gap propagation limits for 6 commercial small diameter explosives were determined at a temperature of 20°C. Appendix A lists the explosives and diameters tested, and the names by which they will be referred to. The results of the initial air gap tests permit the development of scaling relations between air gap propagation sensitivities and charge diameter for Slurry, Water Gel, and Emulsion products.

The report then considers the effect of temperature on the air gap sensitivity results. Tests were conducted at +5°C and -5°C on the 3 types of explosives.

The effect of decoupling the explosive charges from the borehole wall on the air gap sensitivity for the 3 explosive types is then discussed.

Results of tests conducted with sand and water gaps at 20°C are analyzed to determine the effect of these materials on the propagation sensitivity of the 3 explosive types. The results of the sand gap tests permit the development of scaling relations between sand gap sensitivities and charge diameter.

The report concludes with a brief summary of the test results and an outline of the possible application of the results to the mining industry.

2.0 EXPERIMENTAL DESIGN AND INSTRUMENTATION

The experimental design chosen for determining the gap sensitivity of the various explosives is comprised of a series of confined tests in which a donor explosive is separated by a selected distance from the receptor explosive. Appendix B summarizes the lengths of donor and receptor charges for the tests performed. The donor charges used were assumed to be sufficiently long that any increase in donor length would not increase its initiating effectiveness.

The gap distance was varied from shot to shot, employing the Bruceton "Up and Down" method (1,2), with the gap distance being increased or decreased depending on the previous result. Thus, if detonation of the receptor charge occurred, the next shot in the same series (same explosive product, same charge diameter, same length of donor and receptor, same gap material, same temperature) would be tested at a greater gap distance. Conversely, if the receptor failed to detonate, the gap distance would be decreased for the next test. Once the approximate value of the mean gap distance was determined, the interval between testing levels was limited to less than twice the standard deviation of the normally distributed variate gap distance.

This technique for obtaining sensitivity data automatically concentrates testing near the mean and hence, the gap distance at which the probability of cross-propagation is 50% is determined with fewer trials.

A nichrome resistance wire velocity of detonation probe was employed for each of the tests to determine if the receptor charge had detonated. Visual confirmation of receptor failure or detonation was also possible by observing the amount of rock moved by the shot. The velocity of detonation probe is a standard method for monitoring explosive detonation velocities and employs a constant current source, trigger circuit, blast machine, and oscilloscope with photographic capabilities. Figure 1 outlines this monitoring system. The nichrome wire itself must be of high quality in order to ensure that its resistance per unit length is constant.

A diagram of a fully coupled air gap test insitu can be found in Figure 2. The corresponding oscilloscope photographic record is also included. As can be seen from the photograph, the receptor charge detonated and from this record, the velocity of detonation for the donor charge can be readily calculated. The detonation velocities of the receptor charges were not calculated since inaccuracies arise when the shockwave and expanding gases from the donor detonation cause the receptor to move.

The mechanism of cross-propagation is complex. Upon detonation, the donor charge creates a high pressure shock wave and emits hot detonation products travelling at a lower velocity. The intensity of the pressure from a charge varies with its diameter if the velocity of detonation increases with charge diameter. This

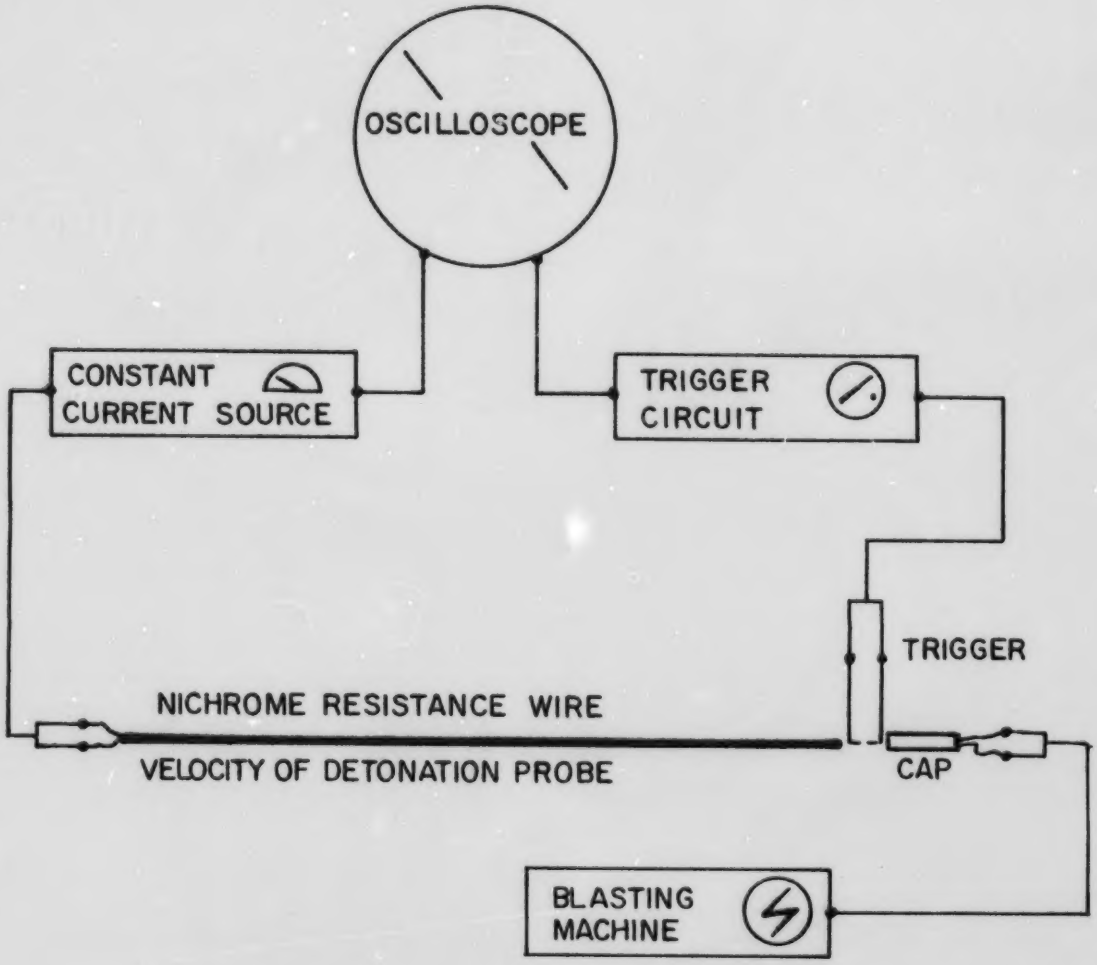


FIGURE 1 : BLAST MONITORING SYSTEM .

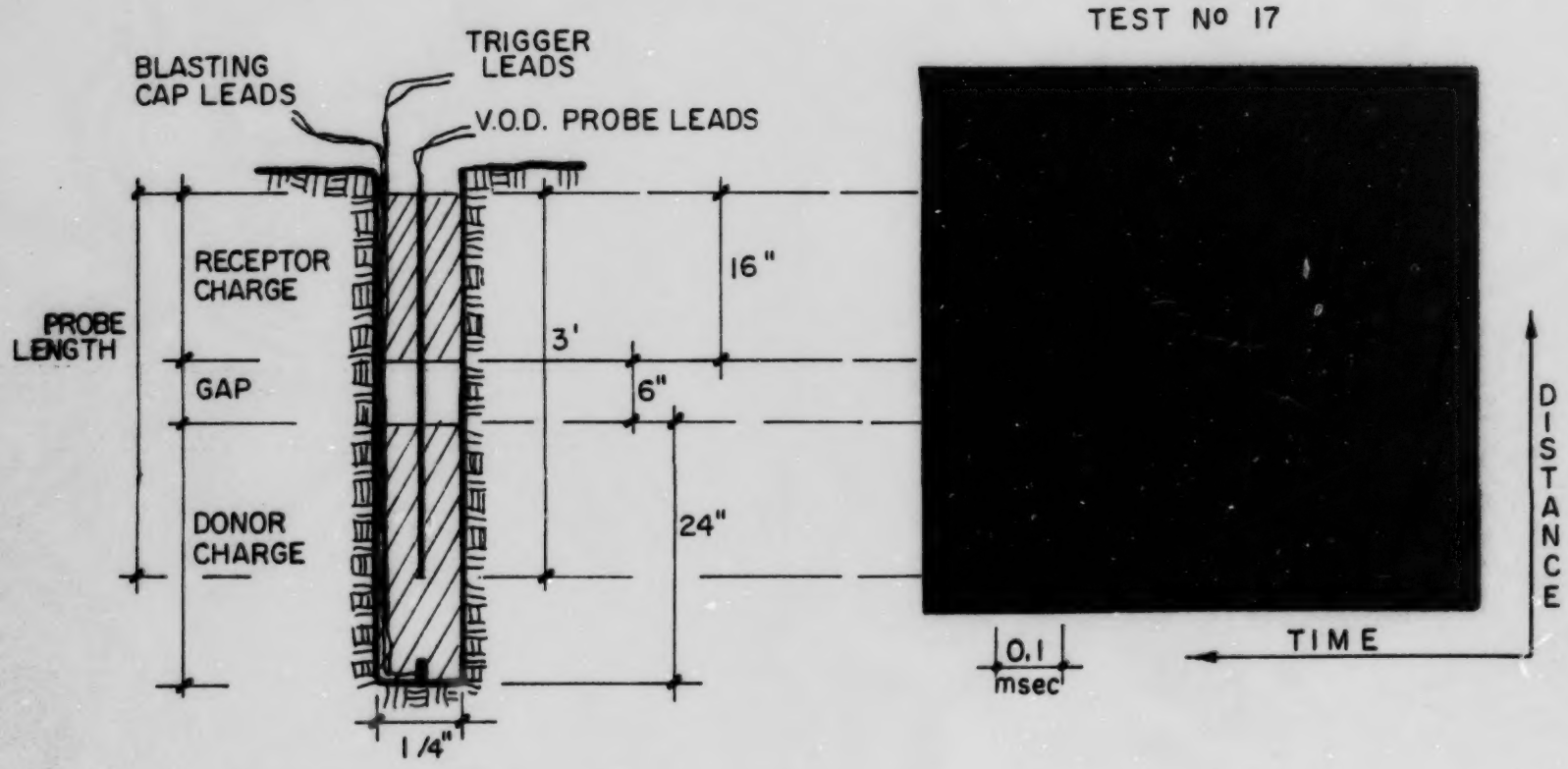


FIGURE 2 : DETERMINATION OF RECEPTOR DETONATION OR FAILURE AND DONOR VELOCITY OF DETONATION FOR FULLY COUPLED CHARGES.

is evidenced in Figure 3 which is a plot of the average velocity of detonation of the donor versus charge diameter for typical products tested. The detonation pressure for a given charge density is proportional to the velocity of detonation squared. Hence, the peak pressure in the initial shock will increase with diameter until a charge diameter is reached beyond which there is no further velocity of detonation increase. In addition, since the length of the detonation head is proportional to the diameter of the charge, the impulse from the end of the charge will increase with diameter.

The magnitude of the air shock pressure and impulse as well as the amount of hot products impacting the receptor charge are dependent on many factors,including,product composition, gap medium, product diameter, product temperature, and degree of confinement. The process is therefore highly complex, and only theoretical generalities will be used in discussing the test results.

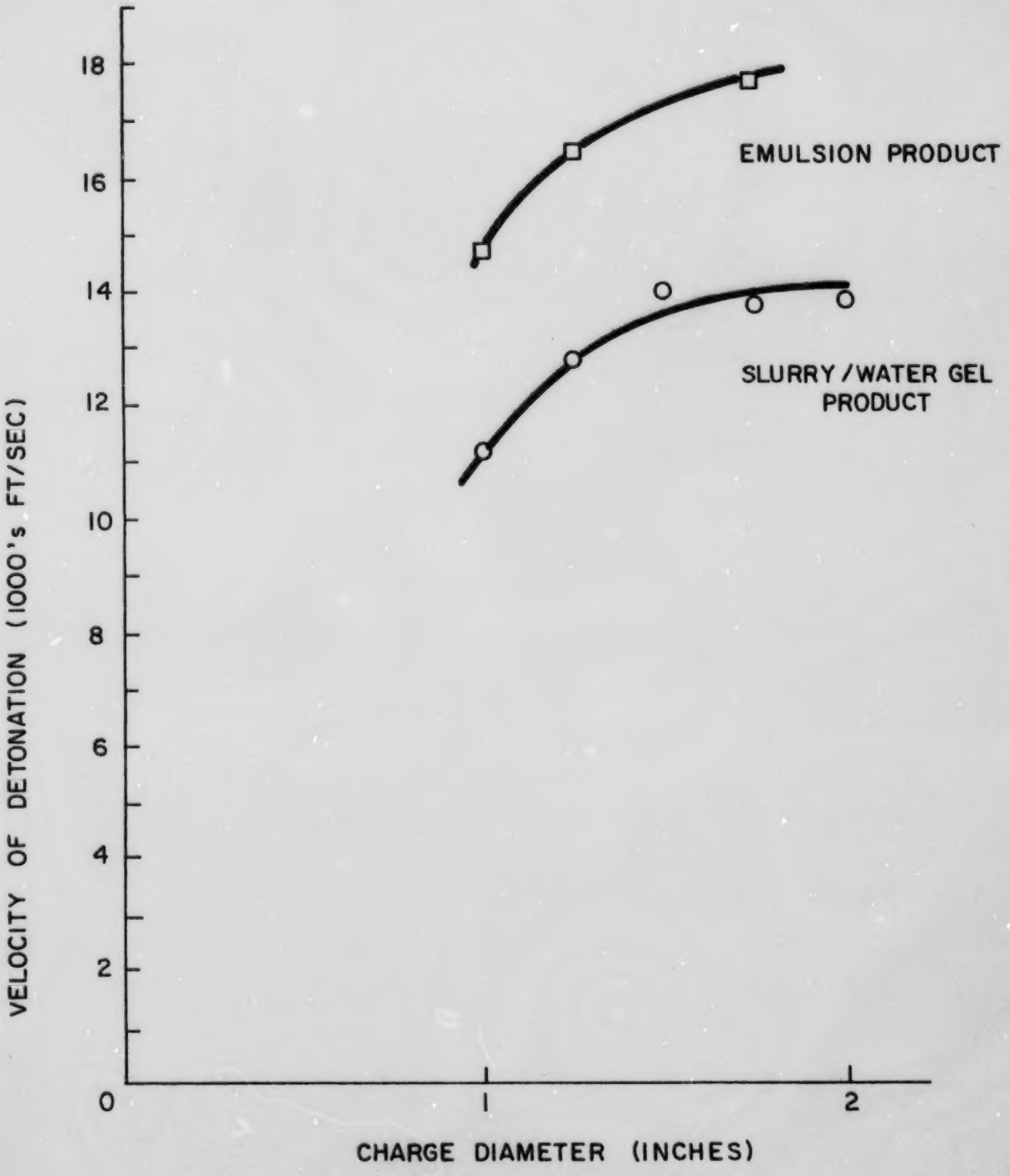


FIGURE 3 : VELOCITY OF DETONATION VERSUS CHARGE DIAMETER CURVES FOR TYPICAL SLURRY/WATER GEL AND EMULSION PRODUCTS TESTED IN GRANITE AT 20° C.

3.0 EXPERIMENTAL RESULTS

3.1 Comparison of Steel Pipe to Granite as a Confining Medium

Steel pipe was initially thought of as being a more economical confining medium than boreholes in granite. Tests were performed to compare the fully coupled air gap sensitivity results obtained with the 1 1/4" diameter glass microbubble sensitized Emulsion confined by various thicknesses of steel pipe to the results obtained when this product was granite confined. Appendix C contains the results for each of the tests performed.

In this case, the "Up and Down" method was not used since it concentrates the data around the mean gap distance. Instead, several tests were taken at various air gap distances in order to compare the distribution of data around the mean for the 5/32" steel and granite confined results. Figure 4 is a plot of these two distributions.

As can be seen, the P50 gap distance (gap distance at which the probability of cross-propagation is 50%) for the two types of confinement is approximately 8 inches and the distributions around the mean are similar.

Appendix D tabulates the average donor velocities of detonation for the various confining methods. The limited velocity and gap results to date indicate that the thickness of the metal, beyond a minimum thickness, may be of little consequence to the test results.

Results suggest that for a particular explosive type,

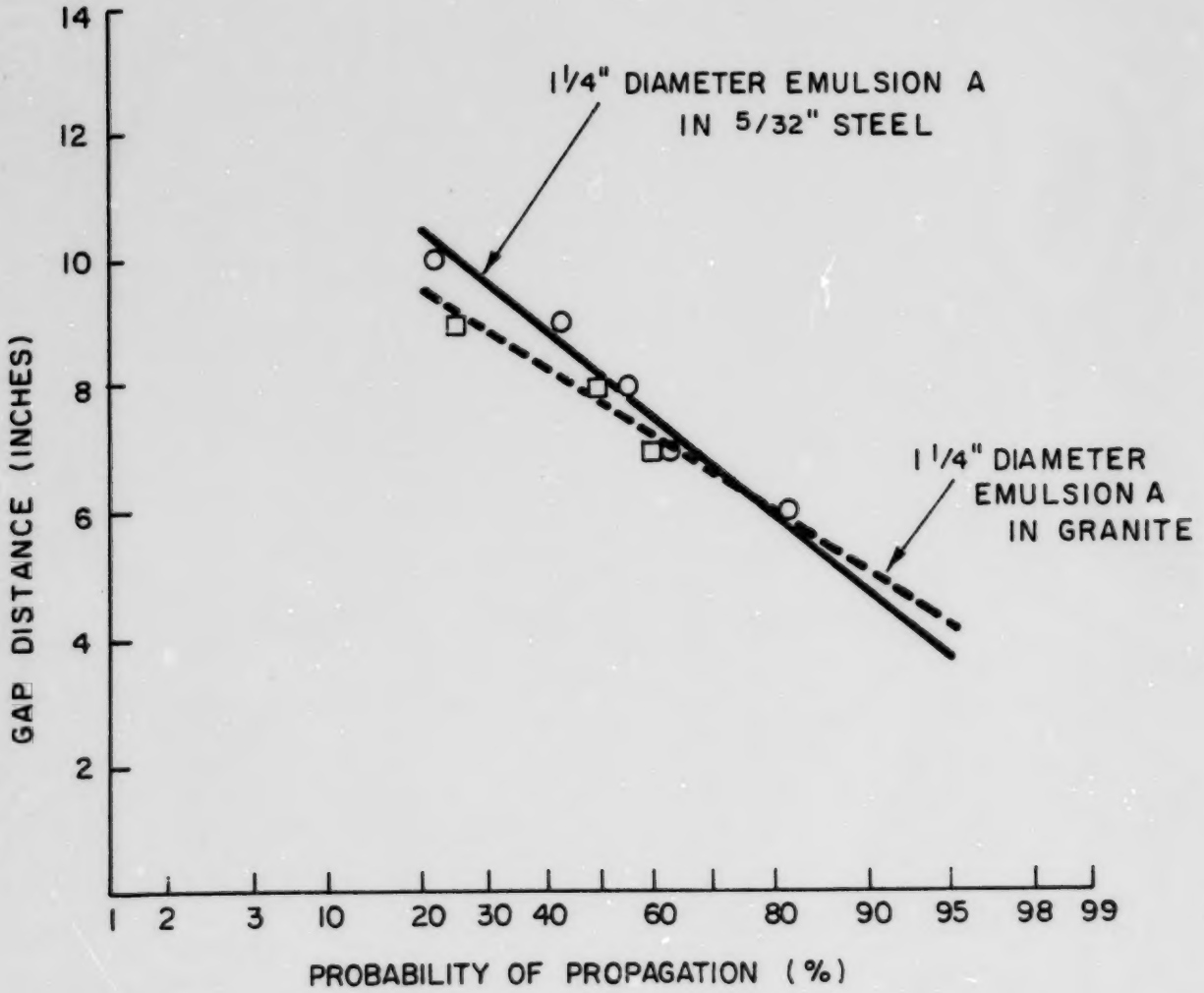


FIGURE 4 : COMPARISON BETWEEN AIR GAP TEST RESULTS IN GRANITE AND STEEL PIPE FOR GLASS MICROBUBBLE SENSITIZED EMULSION.

at a certain charge diameter,the distribution of cross-propagated gap distances around the mean is normal. This theory is substantiated by subsequent results and agrees with the assumptions made in the "Up and Down" method.

Results also suggest that the 5/32" steel pipe is comparable to granite as a confining medium when testing glass microbubble sensitized Emulsion. This comparison cannot however be expanded to include the confinement of Slurry and Water Gel due to the inherent differences in the way these products are sensitized. It was therefore concluded that granite boreholes should be used for subsequent testing.

3.2 Fully Coupled Air Gap Tests at 20°C

Appendix E contains the results for each of the 20°C fully coupled air gap tests performed on the six products. Also included are the "Up and Down" receptor result plots for the products tested under these conditions. The P50 gap distances are shown on these plots.

Table 1 summarizes the P50 gap distances, and Table 2 summaries the average donor velocities of detonation calculated for all of the products, charge diameters, and test conditions.

TABLE 1

SUMMARY OF P50 DISTANCES FOR TESTS PERFORMED

PRODUCT	DIAMETER (inches)	P50: GAP DISTANCE (inches) AT WHICH PROPAGATION PROBABILITY IS 50%. FULLY COUPLED AIR GAP AT 20°C	FULLY COUPLED AIR GAP AT +5°C	FULLY COUPLED AIR GAP AT -5°C	DECOUPLED AIR GAP AT 20°C	FULLY COUPLED SAND GAP AT 20°C	FULLY COUPLED WATER GAP AT 20°C
SLURRY A	1	19	--	--	--	--	--
	2	49	--	--	--	--	--
SLURRY B	1 1/4	29	20	17.5	19	13	28
	1 1/2	29	27	16	--	15	33
	2	47	--	--	--	--	--
WATER GEL A	1	6	N.D.	N.D.	N.D.	5	20
	1 1/4	30	12	6	11	11.5	23
	1 3/4	54	--	--	--	--	--
	2	52	--	--	--	--	--
WATER GEL B	1	28	--	--	--	--	--
	1 1/4	41	--	--	--	--	--
	1 3/4	44	--	--	--	--	--
	2	51	--	--	--	--	--
EMULSION A	1	1.5	1.5	1.5	0.5	1.5	4.5
	1 1/4	8.5	2	2.5	4	4	9.5
	1 3/4	12.5	--	--	--	--	--
EMULSION B	1	0.5	--	--	--	--	--
	1 1/4	3	--	--	--	--	--
	1 3/4	14	--	--	--	--	--

N.D.: NO DETONATION OVER 4 FEET OF CONTINUOUS CHARGE.

TABLE 2

SUMMARY OF AVERAGE DONOR VELOCITY OF DETONATION FOR TESTS PERFORMED

PRODUCT	DIAMETER (inches)	DONOR VELOCITY OF DETONATION											
		FULLY COUPLED AIR GAP AT 20°C		FULLY COUPLED AIR GAP AT +5°C		FULLY COUPLED AIR GAP AT -5°C		DECOUPLED AIR GAP AT 20°C		FULLY COUPLED SAND GAP AT 20°C		FULLY COUPLED WATER GAP AT 20°C	
		ft/sec	km/s	ft/sec	km/s	ft/sec	km/s	ft/sec	km/s	ft/sec	km/s	ft/sec	km/s
SLURRY A	1	11,150	3.39	--	--	--	--	--	--	--	--	--	--
	2	14,150	4.31	--	--	--	--	--	--	--	--	--	--
SLURRY B	1 1/4	11,700	3.56	10,000	3.05	11,400	3.47	10,650	3.25	12,000	3.65	11,650	3.55
	1 1/2	14,000	4.27	14,100	4.30	13,400	4.08	--	--	13,650	4.16	14,000	4.27
	2	13,800	4.21	--	--	--	--	--	--	--	--		
WATER GEL A	1	10,700	3.26	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	10,500	3.20	10,100	3.08
	1 1/4	12,900	3.93	11,200	3.41	11,100	3.38	11,800	3.60	12,250	3.73	12,350	3.76
	1 3/4	13,500	4.11	--	--	--	--	--	--	--	--	--	--
	2	13,800	4.20	--	--	--	--	--	--	--	--	--	--
WATER GEL B	1	11,650	3.55	--	--	--	--	--	--	--	--	--	--
	1 1/4	13,600	4.14	--	--	--	--	--	--	--	--	--	--
	1 3/4	13,950	4.25	--	--	--	--	--	--	--	--	--	--
	2	13,100	3.98	--	--	--	--	--	--	--	--	--	--
EMULSION A	1	14,450	4.41	16,650	5.07	15,600	4.75	15,150	4.62	16,100	4.91	15,200	4.63
	1 1/4	17,250	5.25	15,700	4.79	16,750	5.11	16,850	5.14	18,100	5.50	16,500	5.03
	1 3/4	18,100	5.51	--	--	--	--	--	--	--	--	--	--
EMULSION B	1	14,950	4.55	--	--	--	--	--	--	--	--	--	--
	1 1/4	15,700	4.79	--	--	--	--	--	--	--	--	--	--
	1 3/4	17,300	5.27	--	--	--	--	--	--	--	--	--	--

N.D.: NO DETONATION OVER 4 FEET OF CONTINUOUS CHARGE.

Figure 5 contains plots of 1 1/4" diameter Water Gel B and Emulsion A fully coupled air gap distributions at 20°C. For a 1 1/4" diameter Emulsion charge the P95 gap distance (gap distance at which the probability of cross-propagation is 95%) is 3.5 inches less than the P50 gap distance and 7 inches less than the P05 gap distance. For a 1 1/4" diameter Water Gel charge the P95 gap distance is 4 inches less than the P50 gap distance and 8 inches less than the P05 gap distance.

When the 20°C fully coupled P50 air gap distances in Table 1 are plotted versus charge diameter, two well correlated lines are evident. These two P50 air gap distance lines are shown in Figure 6. One line represents the combined Slurry/ Water Gel P50 cross-propagation probability curve, while the other line represents the Emulsion P50 cross-propagation probability curve. The equations of these two lines are estimated relationships between charge diameter and gap distance at 50% cross-propagation probability for charge diameters greater than 1 inch. These lines have been extrapolated beyond the 2 inches maximum charge diameter of the tests.

The P05 and P95 lines for both of these product types have also been plotted on Figure 6. The positions of these lines were estimated from both the Water Gel and Emulsion 1 1/4 inch charge diameter distribution curves of Figure 5 and from observed variations in results of the larger diameter tests. The P05 and P95 lines have also likewise been extrapolated.

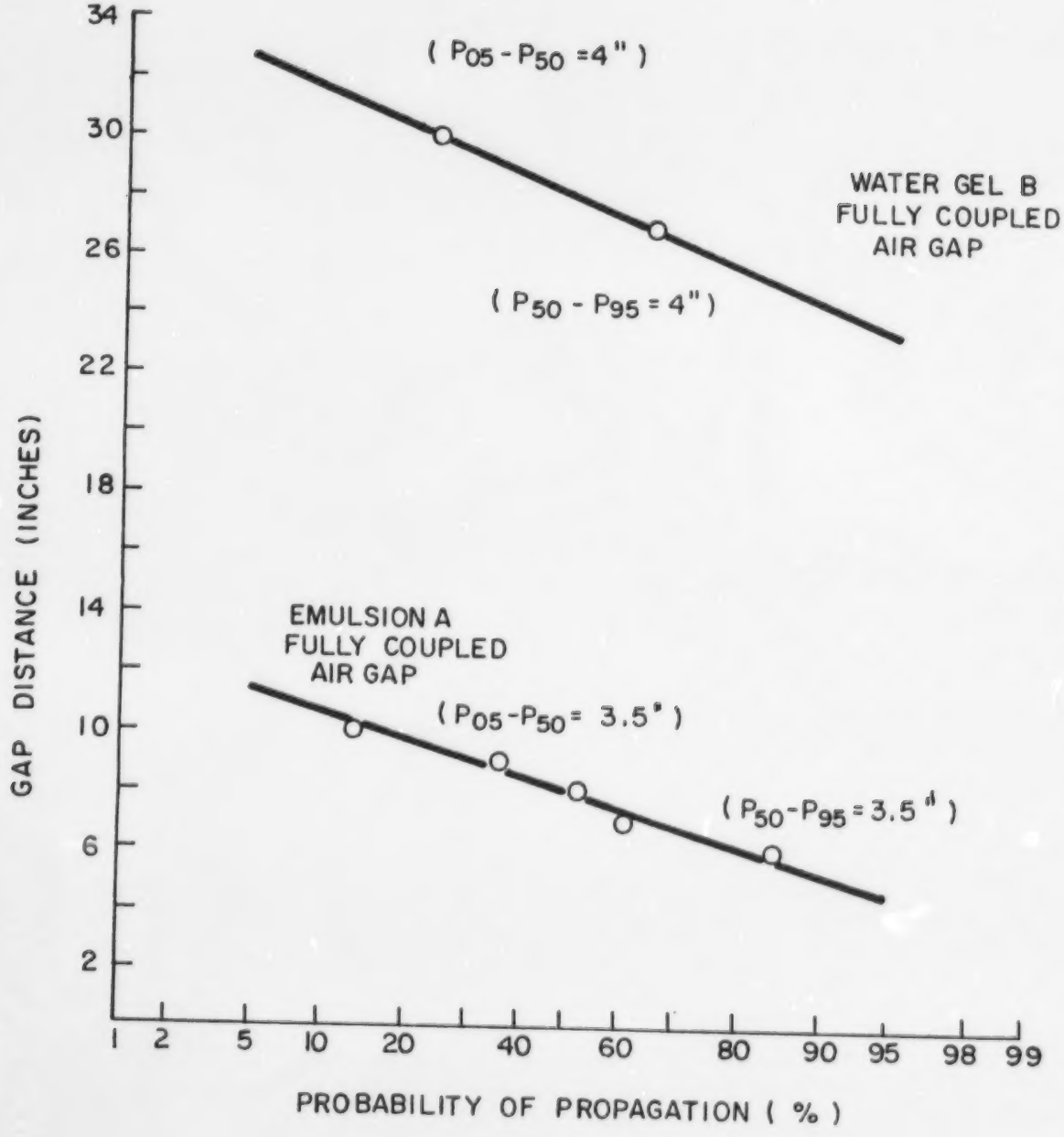


FIGURE 5 : AIR GAP DISTANCE DISTRIBUTIONS FOR 1 1/4" DIAMETER WATER GEL AND EMULSION CHARGES AT 20° C.

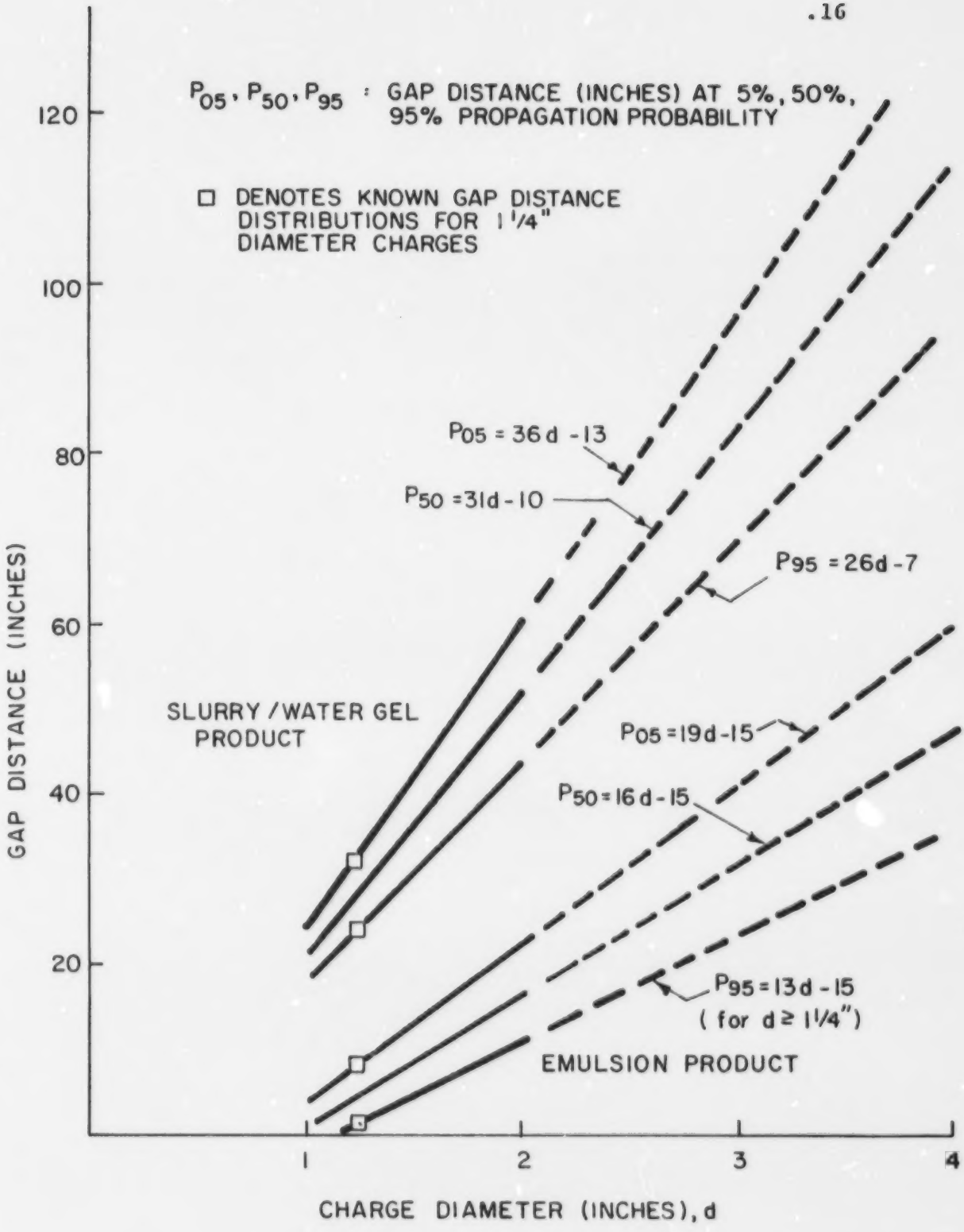


FIGURE 6 : ESTIMATED PROPAGATION PROBABILITY CURVES, FULLY COUPLED AIR GAP RESULTS FOR TYPICAL SLURRY / WATER GEL AND EMULSION PRODUCTS AT 20° C.

Results indicate that, given the same charge diameter, fully coupled Slurry products at 20°C will generally propagate across the same air gap distance as fully coupled Water Gel products at 20°C.

Emulsion products however are far less able to propagate across the air gaps. They performed very poorly when compared to the Slurry/Water Gel products. This poor performance could be due to the fact that the emulsions tested were sensitized using (hollow) glass microbubbles and the Slurry/Water Gel products were possibly sensitized by air bubbles entrapped in the gel structure and with chemical sensitizers. It obviously takes more energy for glass microbubbles than it takes for entrapped air bubbles to act as detonation centres for an explosive. This could be due to the physical strength of the microbubble itself, to the fact that non-reactive silica would be on the outside of the "hot-spot" surface, or possibly due to the low gas content inside the microbubble (the pressure inside the bubble is low) so that it requires a higher degree of compression to arrive at the same energy level as a gas bubble at atmospheric pressure.

Results also indicate that there is a linear relationship between charge diameter and gap distance for various cross-propagation probabilities. The relationships suggested are based on test results for charge diameters between 1 and 2 inches. The assumption that a linear relationship exists between gap distance

and charge diameter agrees quite well with the theory that the impulse off the end of a cylindrical explosive charge varies with the charge diameter in an approximately linear manner. However, it is well recognized that the mechanism for the onset of detonation, due to the shock and the impact from the hot explosive products on the receptor charge, is extremely complex in this type of testing.

3.3 Fully Coupled Air Gap Tests at 5°C and -5°C

Appendix F contains the results of the 5°C and -5°C fully coupled air gap tests performed on the three products. Also included are the "Up and Down" receptor result plots for the products and the calculated P50 gap distances.

Table 1 indicates a large reduction in the P50 air gap distance for Water Gel A when the temperature is decreased from 20°C to 5°C. At this temperature the 4 feet long, 1 inch diameter charge failed to detonate. The 1 1/4 inch diameter charge cross-propagated a distance of only 40% of the distance it cross-propagated at 20°C.

In comparison to the Water Gel product, the P50 air gap distance that the Slurry and Emulsion products propagated across at 5°C was only marginally less than the distances they cross-propagated at 20°C.

Table 1 also indicates a large reduction in the P50 air gap distance for Water Gel A when the temperature is decreased to -5°C. Once again the 1" diameter charge failed

completely and the 1 1/4" diameter charge only propagated across a P50 air gap distance equal to 20% of the distance it propagated across at 20°C.

The Slurry products'P50 air gap distances cross-propagated at -5°C are noticeably reduced from the distances cross-propagated at 20°C. At -5°C both the 1 1/4 and 1 1/2 inch diameter charges have P50 air gap distances approximately equal to 60% of the cross-propagation distances that they attained at 20°C.

The effect of decreasing the temperature to -5°C on the gap propagation results for the Emulsion product is minimal.

Results indicate that the ability of fully coupled Water Gel products to propagate across air gaps is more sensitive than that of Slurry or Emulsion products to a decrease in temperature. At 5°C the critical diameter of the Water Gel product was greater than 1 inch.

The propagation sensitivity of Emulsion products seems to be the least effected by a decrease in temperature. At decreased temperatures the air bubbles that help sensitize the Slurry/Water Gel products become pre-compressed. This makes them less effective as initiation centres for the explosive. The hollow microbubbles in Emulsion do not undergo this pre-compression with a decrease in temperature and remain as effective as they were at 20°C. The Slurry products may contain more

chemical sensitizers than the Water Gel products which would explain the Slurry's better gap sensitivity at lower temperatures.

It is interesting to note that the donor velocity of detonation for the Water Gel product decreases faster with a decrease in temperature than does the donor velocity of detonation for the Slurry product. The Emulsion donor velocity of detonation remained relatively constant throughout this temperature range. These respective changes in donor velocities correspond with changes in donor detonation pressures which correspond with changes in the respective gap sensitivities.

3.4 Decoupled Air Gap Tests at 20°C

The results of testing Slurry B, Water Gel A, and Emulsion A at charge diameters of 1 and 1 1/4 inches in 1 3/4 inch diameter granite boreholes are contained in Appendix G. Also included in this appendix are the "Up and Down" receptor result plots and the calculated P50 gap distances.

Figure 7 illustrates a decoupled 4 foot continuous charge insitu. Initially, the 3 products were tested as a 4 feet long decoupled continuous charge in order to determine if the decoupling had an effect on the products' ability to propagate continuously. Figure 7 also contains the oscilloscope's photographic record for Test #367 which was a test of the 1 inch diameter Water Gel A product decoupled in a 1 3/4 inch diameter hole. It is evident that this product failed to propagate continuously when decoupled from the borehole wall in this manner.

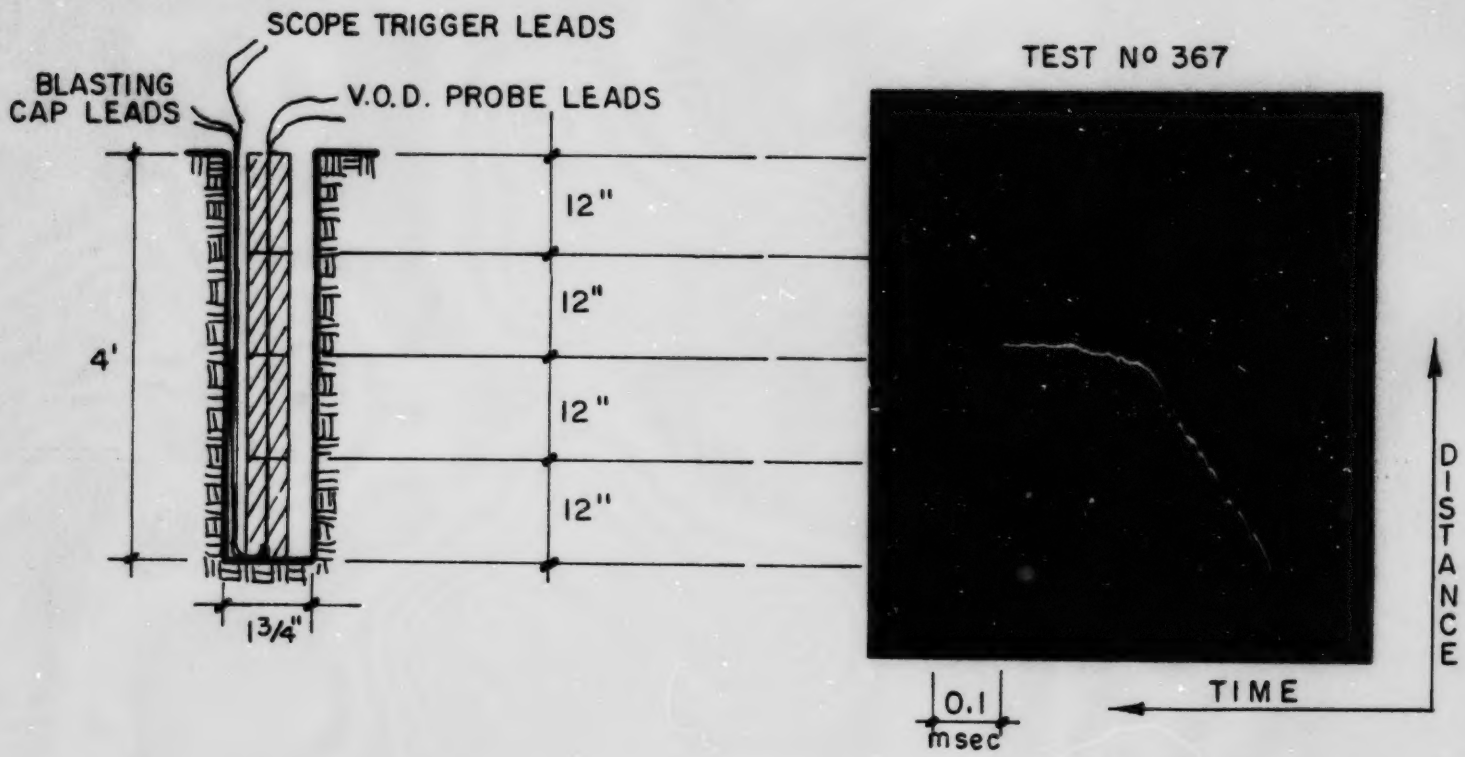


FIGURE 7 : DETERMINATION OF "CHANNEL EFFECT" USING 4' LONG DECOUPLED CHARGES IN 1¾" DIAMETER HOLES IN GRANITE.

Appendix H lists the results of the 4 feet long decoupled charge tests. Figure 8 presents these results in graphical form.

The results of the 4 feet long decoupled continuous charge tests indicate that the Water Gel product can be desensitized to a point of failure through the "Channel-Effect". One might expect the same conclusion to be made for Slurry products however. Using the available Slurry B product diameters, Slurry failure was not induced during these tests.

The desensitizing process is caused by detonation pressures in the air annulus around the charge travelling in front of the detonation wavefront. These pressures can pre-compress and reduce the effectiveness of the air bubbles in a product thereby desensitizing it before the detonation wavefront arrives. The degree of a product's desensitization depends on the composition of the product and on the degree of decoupling from the borehole wall.

Table 1 indicates a large reduction in the cross-propagation air gap distance for the decoupled Water Gel and Slurry products. The 1 inch diameter Emulsion product detonated continuously over 4 feet length of charge, however, its average cross-propagation air gap distance was reduced from 1.5 inches when fully coupled to 0.5 inches when decoupled. The 1 1/4 inch diameter Emulsion product also experienced a decrease in its ability to propagate across an air gap when decoupled.

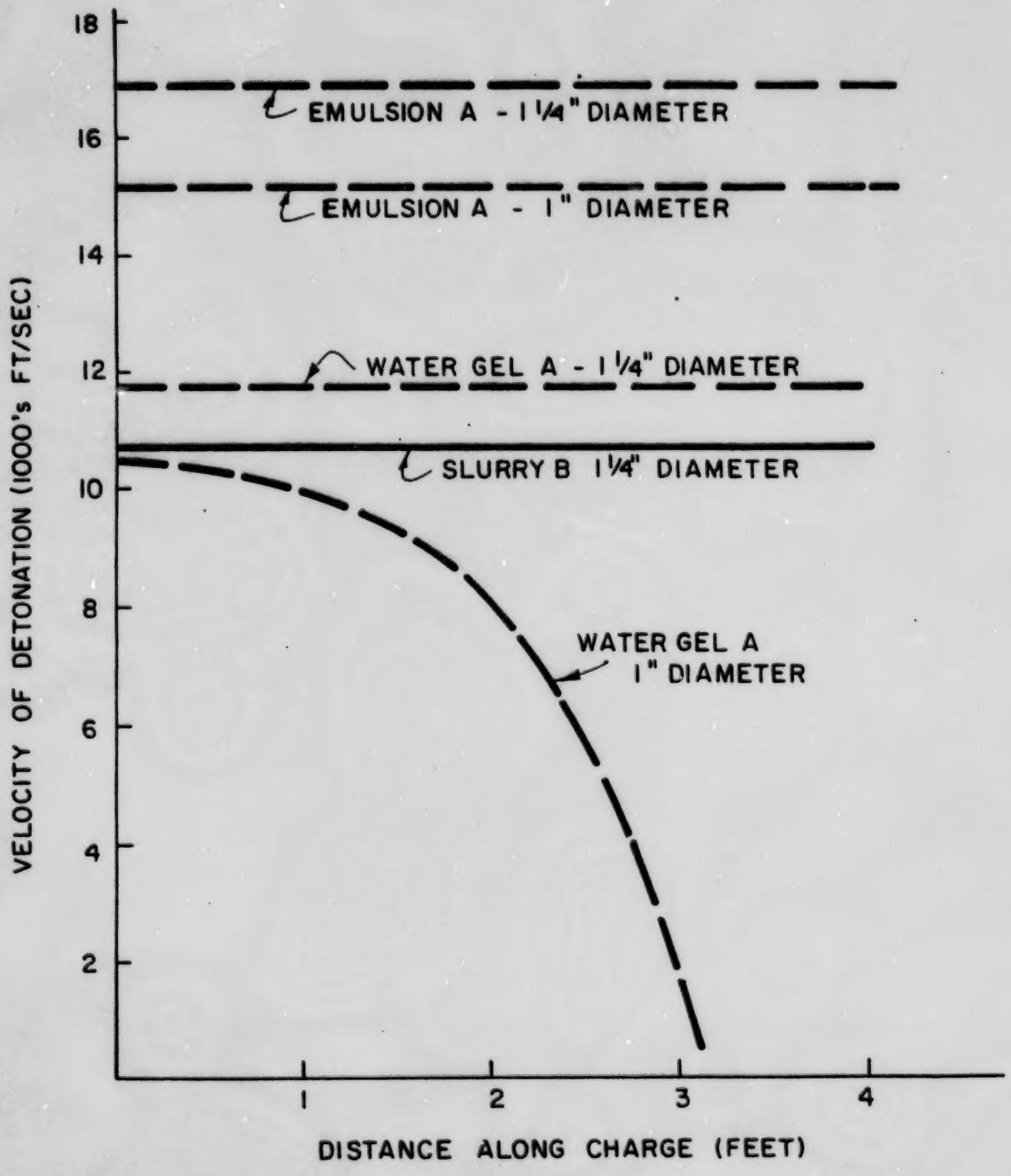


FIGURE 8 : RESULTS OF THE "CHANNEL EFFECT" EVALUATION IN 1 3/4" DIAMETER BOREHOLES FOR THE THREE PRODUCTS TESTED.

When a confined donor charge is fully coupled, gas expansion upon detonation is directed in an axial direction towards the receptor charge. However, when the donor charge is decoupled part of this gas expansion is in the radial direction thereby decreasing the pressure and the amount of hot products impacting the receptor charge. This reduces the product's ability to cross-propagate an air gap.

3.5 Fully Coupled Sand Gap Tests at 20°C

Appendix I contains the results for each of the 20°C fully coupled sand gap tests performed on the three products. Also included are the "Up and Down" receptor result plots and the calculated P50 gap distances.

Figure 9 contains plots of 1 1/4 inch diameter Emulsion A fully coupled sand and air gap distributions at 20°C. The distributions of results around the mean are similar for the two types of gap tests.

When the fully coupled P50 sand gap distances in Table 1 are plotted versus charge diameter, two well correlated lines are evident. These two P50 sand gap distance lines are shown in Figure 10. As in the case of the results from the fully coupled air gap tests at 20°C, one line represents the combined Slurry/Water Gel P50 cross-propagation probability curve; the other line represents the Emulsion P50 cross-propagation probability curve. The equations of these two lines are estimated

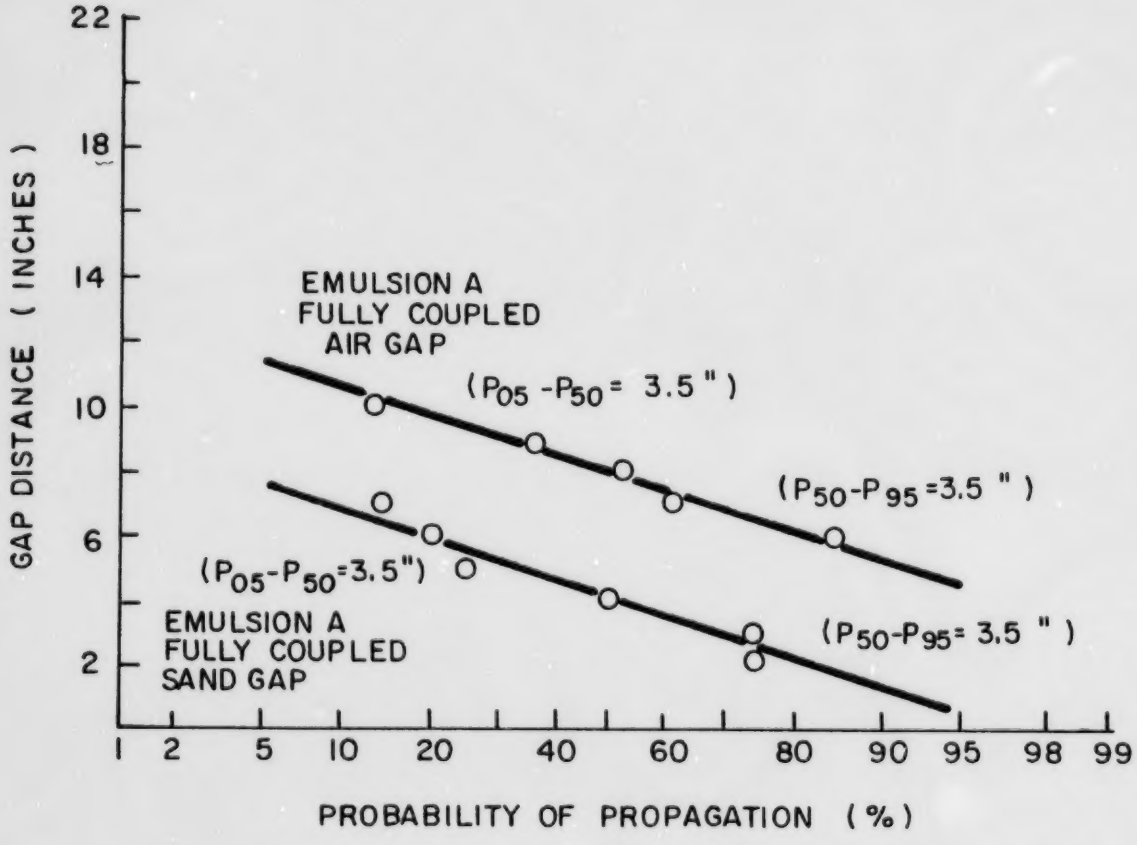


FIGURE 9 : AIR AND SAND GAP DISTANCE DISTRIBUTIONS FOR 1 1/4" DIAMETER EMULSION CHARGES AT 20 °C.

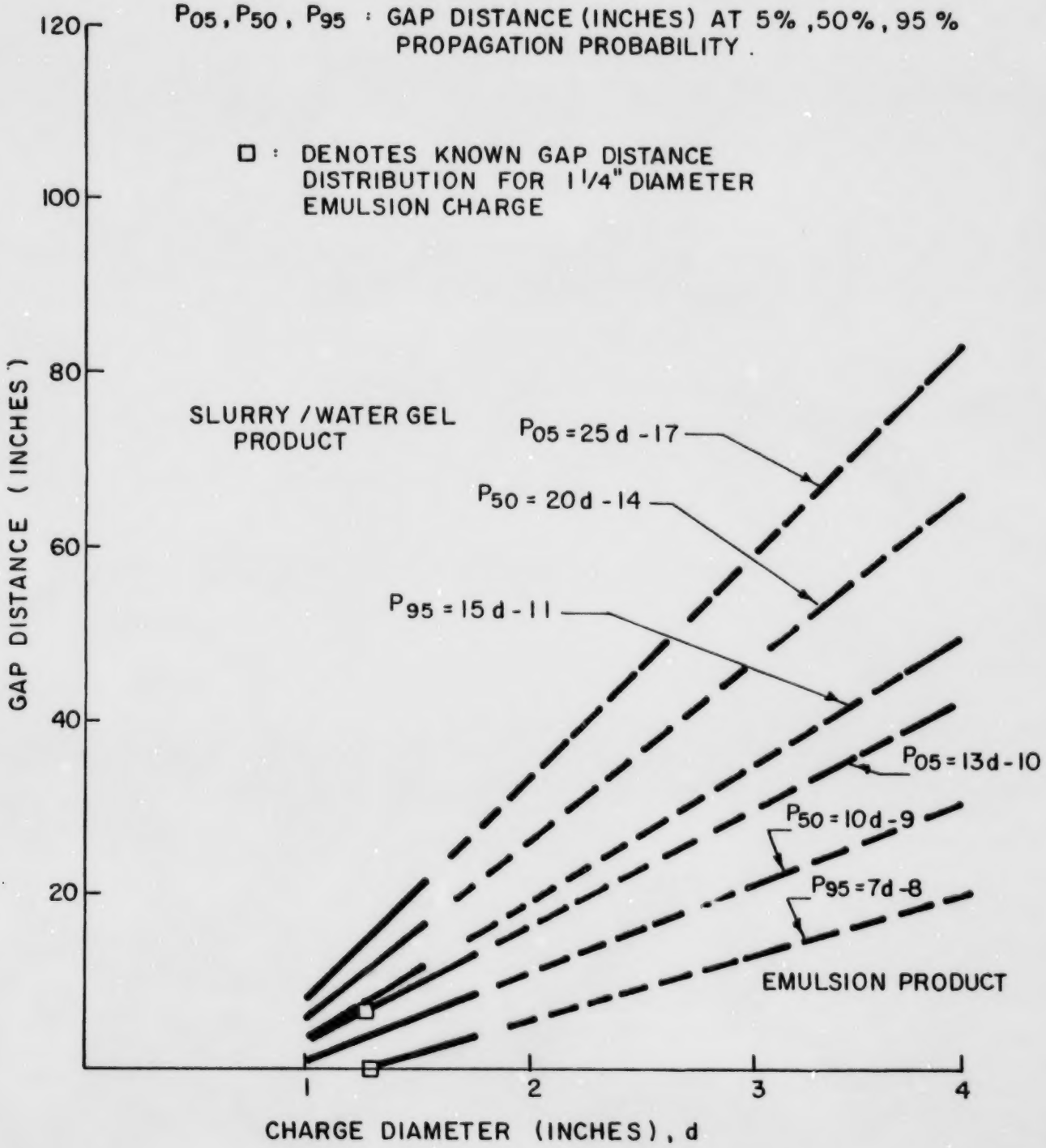


FIGURE 10 : ESTIMATED PROPAGATION PROBABILITY CURVES, FULLY COUPLED SAND GAP RESULTS FOR TYPICAL SLURRY / WATER GEL AND EMULSION PRODUCTS AT 20°C.

relationships between charge diameter and sand gap distance at 50% cross-propagation probability for charge diameters greater than 1 inch. These lines have been extrapolated beyond the maximum 1 1/2 inches charge diameter of the tests.

The P05 and P95 lines for both of these products are also shown in Figure 10. The positions of these lines were estimated from the Emulsion 1 1/4 inch charge diameter curves of Figure 9 and the Water Gel 1 1/4 inch charge diameter distribution curve of Figure 5. The P05 and P95 lines have also been extrapolated beyond the maximum 1 1/2 inch charge diameter of the tests.

Figure 11 shows the two P50 sand gap distance lines as well as the two P50 air gap distance lines and illustrates the decrease in cross-propagated gap distance for a given charge diameter when sand is used as the gap material instead of air. This decrease in cross-propagation distance could be due to the fact that air transfers pressure better than sand and that the sand may have interfered with the impact of the receptor charge by hot detonation products from the donor.

3.6 Fully Coupled Water Gap Tests at 20°C

Appendix J contains the results for each of the 20°C fully coupled water gap tests performed on the three products. Also included are the "Up and Down" receptor result plots

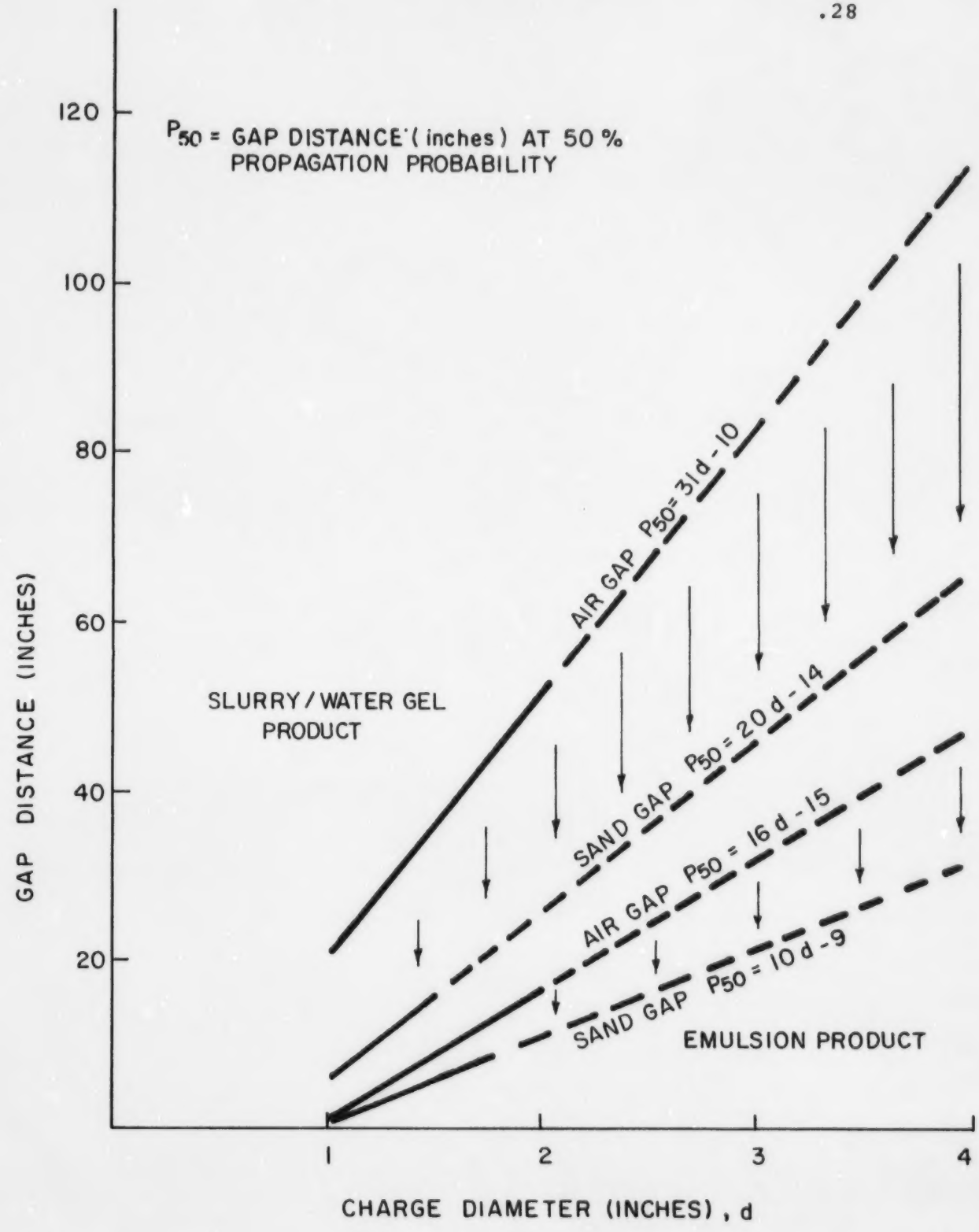


FIGURE 11 : ESTIMATED 50% PROPAGATION PROBABILITY CURVES ILLUSTRATING THE EFFECT OF SAND AS A GAP MATERIAL FOR TYPICAL FULLY COUPLED SLURRY / WATER GEL AND EMULSION PRODUCTS AT 20° C.

and the calculated P50 gap distances.

When the fully coupled P50 water gap distances in Table 1 are plotted versus charge diameter, two well correlated lines are evident. These two P50 water gap distance lines are shown in Figure 12 with the two P50 air gap distance lines. As in the case of the results from the fully coupled air and sand gap tests at 20°C, one of the P50 water gap lines represents the combined Slurry/Water Gel 50% cross-propagation probability curve; the other P50 water gap line represents the Emulsion 50% cross-propagation probability curve. The equations of these two water gap P50 lines are estimated relationships between charge diameter and water gap distance at 50% cross-propagation probability for charge diameters greater than 1 inch. These lines have been extrapolated beyond the maximum 1 1/2 inches charge diameter of the tests.

As the results presented in Figure 12 indicate, there is a decrease in the cross-propagated gap distance for a given Slurry/Water Gel charge diameter when water is used as the gap material instead of air. This decrease in cross-propagated distance can be explained as follows. The water will cool the hot detonation products from the donor charge thereby rendering them less effective as initiators on the receptor charge.

However, water is a better medium than air for the transfer of pressure. Hence the increase in the cross-propagated gap distance for Emulsion when water is used as the gap material instead of air can also be expected.

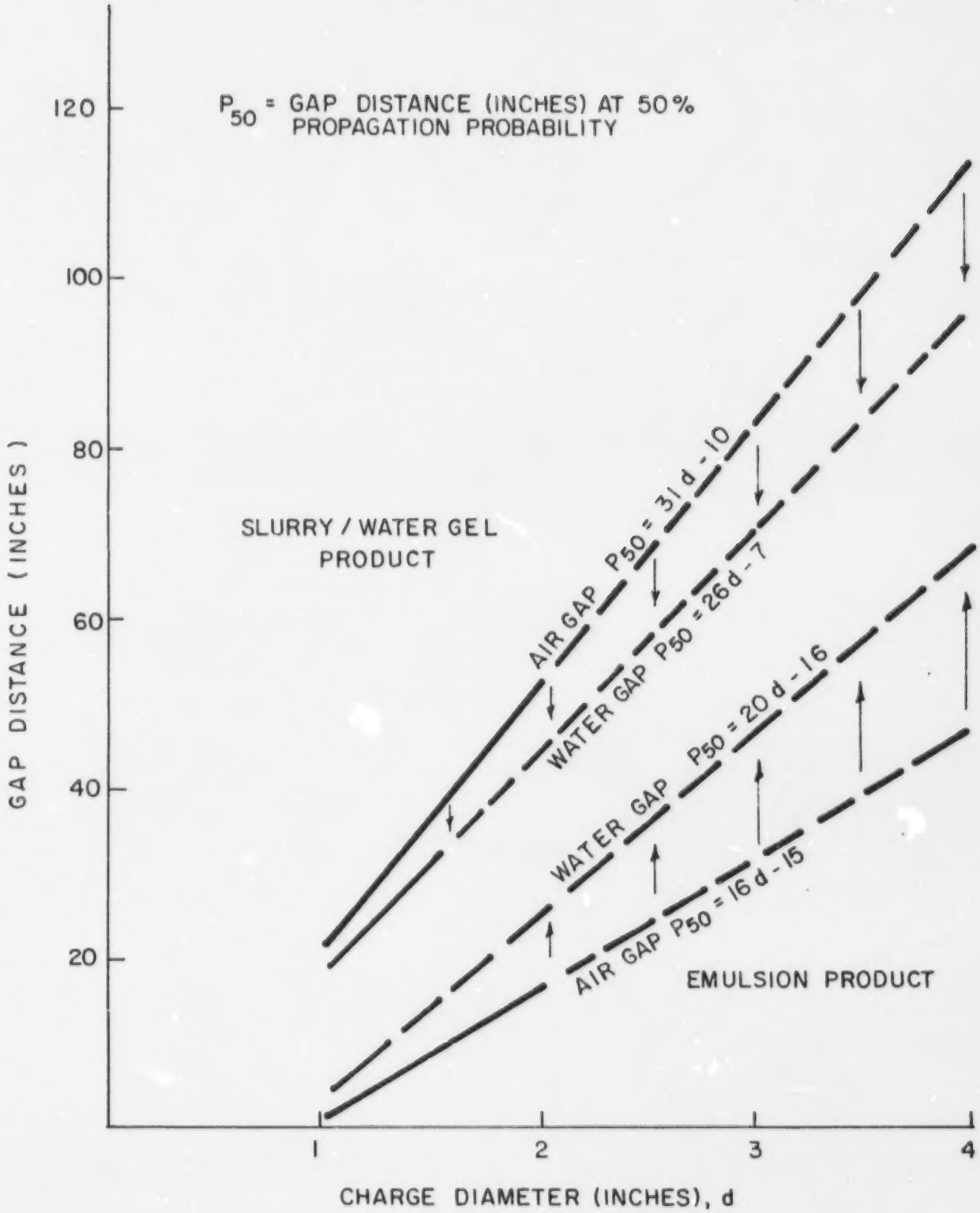


FIGURE 12 : ESTIMATED 50% PROPAGATION PROBABILITY CURVES ILLUSTRATING THE EFFECT OF WATER AS A GAP MATERIAL FOR TYPICAL FULLY COUPLED SLURRY/ WATER GEL AND EMULSION PRODUCTS AT 20° C.

From the results of these tests it seems that hot detonation products from the donor have a greater effect on the propagation sensitivity of Slurry/Water Gel products than they do on the Emulsion products. Conversely, the pressures exerted on the receptor seem to have a greater effect on the propagation sensitivity of the Emulsion products than they do on the Slurry/Water Gel products.

Table 3 summarizes the scaling relationships between charge diameter and propagated gap distance derived from the results of the tests performed.

TABLE 3

SUMMARY OF SCALING RELATIONS BETWEEN CHARGE DIAMETER AND PROPAGATED GAP DISTANCE FOR THE VARIOUS TESTS PERFORMED

GAP MATERIAL	SCALING RELATION BETWEEN GAP DISTANCE, g (inches) FOR CHARGE DIAMETER, d (inches) AT A PROBABILITY OF PROPAGATION, P (percent)					
	FULLY COUPLED EMULSION PRODUCT AT 20°C			FULLY COUPLED SLURRY/WATER GEL PRODUCT AT 20°C		
	P = 5%	P = 50%	P = 95%	P = 5%	P = 50%	P = 95%
AIR	g = 19d - 15	g = 16d - 15	g = 13d - 15	g = 36d - 13	g = 31d - 10	g = 26d - 7
SAND	g = 13d - 10	g = 10d - 9	g = 7d - 8	g = 25d - 17	g = 20d - 14	g = 15d - 11
WATER	---	g = 20d - 16	---	---	g = 26d - 7	---

4.0 CONCLUSIONS

1. The small diameter Emulsion products were shown to have a very poor cross-propagation sensitivity for all test conditions, with a 1" cross-propagated gap distance at 1" diameter. Obviously problems could be experienced with loading small diameter emulsion cartridged products. Bulk charging operations in this case would appear to be far superior. However dynamic shock effects on the microbubbles from holes fired on previous delay periods would be more pronounced with this type of loading method.

2. In contrast to the Slurry and Water Gel products, the propagation sensitivity of the Emulsion remained constant over the range of temperatures tested and when sand was used as the gap material instead of air. The cross-propagated water gap distance was greater than the cross-propagated air gap distance for the Emulsion product. This is in sharp contrast to the results obtained for the Slurry and Water Gel products where the cross-propagated water gap distance was less than the cross-propagated air gap distance. Decoupling of the charges resulted in a decrease in distances cross-propagated for all products tested.

3. The propagation sensitivity of the Water Gel products varied more than the Slurry or Emulsion products.

The 1 inch diameter Water Gel product failed when fully coupled at 5°C and when it was decoupled in a 1 3/4 inch diameter hole.

4. Due to the complex nature of the gap cross-propagation mechanism only generalities could be applied to the test results.

5. The results allowed scaling laws to be derived relating charge diameter to air, sand, and water gap distances at 5, 50 and 95 percent cross-propagation pobabilities. The gap distance results are approximately normally distributed around the mean and as such the determination of the 0 and 100 percent cross-propagation probability scaling laws was not feasible.

6. Although testing concentrated on small charge diameters the scaling laws have been estimated as being applicable to larger charge diameters.

7. Example #1: Sand gap distances for separating 6 1/2" diameter Slurry and Emulsion charges in order to avoid cross-propagation:

Product	P05 Scaling Law	Sand Gap Distance
Slurry	25d - 17	12.5 ft
Emulsion	13d - 10	6.5 ft

As can be seen, the sand gap distances at 5% cross-propagation are 12.5 ft for the Slurry product and 6.5 ft for the Emulsion product. It should be emphasized that these are the estimated

distances at 5% cross-propagation probability and should be increased to ensure 0% cross-propagation probability.

8. Applications of Example 1 would be in underground stoping operations where large diameter holes may be decked with explosives and the decks are individually primed to reduce blast vibration. Any cross-propagation of the sand gaps would result in increased vibration and decks shooting out of sequence causing poor rock fragmentation.

An additional application would be for 12 1/4" diameter boreholes containing slurry used in explosive casting for draglines. In many such instances the block to be cast is presplit and during the presplit operation the waste is moved up to 3 ft along the flat lying coal seam. In addition preexisting fractures are opened up. We have witnessed cross-propagation distances in high-speed blast movies of up to 30 to 35 m. The relationship developed here would indicate 36' for 5% probability of cross-propagation. This really is quite a noteworthy finding.

9. Example #2: Air gap distances for separating 2" diameter Slurry and Emulsion charges in order to assure cross-propagation.

Product	P95 Scaling Law	Air Gap Distance
Slurry	26d - 7	3 1/2 ft
Emulsion	13 d - 15	1 ft

As can be seen, the air gap distances at 95% cross-propagation are 3.5 ft for the Slurry product and 1 ft for the Emulsion product. It should be emphasized that these are the estimated distances at 95% cross-propagation probability and should be decreased to ensure 100% cross-propagation probability.

10. Applications of Example 2 would be in bench blasting operations where holes may be decked with explosives to decrease the explosive consumption. The holes are bottom deck initiated and the design calls for the gaps between decks to be cross-propagated.

11. Cross-propagated gap distances can be estimated for Slurry/Water Gel and Emulsion type products at a given charge diameter. The accuracy of these estimates at large charge diameters should be verified in future field tests.

12. Mining operations use free poured or pneumatically loaded AN/FO as their primary dry hole blasting agent whenever possible. This is a result of AN/FO's economic attractiveness and its good performance. Future research on propagation sensitivity should include AN/FO products.

REFERENCES

1. Brownlee, K.A. et. al., "The Up and Down Method with Small Samples", J. Am. Stat. Assoc., v. 48, pp. 262-277.

2. Dixon, W.J., and Massey, F.M., "Introduction to Statistical Analysis", McGraw-Hill Book Co. Inc., New York, 2nd Ed., 1957, pp. 488.

APPENDIX A

NAMES USED FOR EXPLOSIVE PRODUCTS TESTED

APPENDIX B

EXPERIMENTAL ARRANGEMENTS

OF DONOR AND ACCEPTOR CHARGES.

EXPERIMENTAL ARRANGEMENTS OF DONOR AND ACCEPTOR CHARGES

PRODUCT	DIAMETER (inches)	LENGTH (inches) OF DONOR CHARGE AND ACCEPTOR CHARGE											
		FULLY COUPLED AIR GAP AT 20°C		FULLY COUPLED AIR GAP AT +5°C		FULLY COUPLED AIR GAP AT -5°C		DECOUPLED AIR GAP AT 20°C		FULLY COUPLED SAND GAP AT 20°C		FULLY COUPLED WATER GAP AT 20°C	
		donor	acceptor	donor	acceptor	donor	acceptor	donor	acceptor	donor	acceptor	donor	acceptor
SLURRY A	1	12	12	-	-	-	-	-	-	-	-	-	-
	2	16	16	-	-	-	-	-	-	-	-	-	-
SLURRY B	1 1/4	12	12	12	12	12	12	12	12	12	12	12	12
	1 1/2	16	16	12	12	12	12	16	16	16	16	16	16
	2	16	16	-	-	-	-	-	-	-	-	-	-
WATER GEL A	1	12	12	12	12	12	12	12	12	12	12	12	12
	1 1/4	12	12	12	12	12	12	12	12	12	12	12	12
	1 3/4	12	12	-	-	-	-	-	-	-	-	-	-
	2	16	16	-	-	-	-	-	-	-	-	-	-
WATER GEL B	1	12	12	-	-	-	-	-	-	-	-	-	-
	1 1/4	16	16	-	-	-	-	-	-	-	-	-	-
	1 3/4	16	16	-	-	-	-	-	-	-	-	-	-
	2	16	16	-	-	-	-	-	-	-	-	-	-
EMULSION A	1	12	12	8	8	8	8	12	12	12	12	16	16
	1 1/4	24	16	8	8	8	8	12	12	24	16	16	16
	1 3/4	16	16	-	-	-	-	-	-	-	-	-	-
EMULSION B	1	12	12	-	-	-	-	-	-	-	-	-	-
	1 1/4	12	12	-	-	-	-	-	-	-	-	-	-
	1 3/4	12	12	-	-	-	-	-	-	-	-	-	-

APPENDIX C

EXPERIMENTAL RESULTS COMPARING STEEL PIPE AND GRANITE AS CONFINING MEDIUMS FOR GLASS MICROBUBBLE SENSITIZED EMULSION.

FULLY COUPLED AIR GAP TESTS AT 20°C

CONFINING MEDIUM	PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
GRANITE	EMULSION A	1 1/4	11	8	16,000	N
			12	7.5	16,500	Y
			13	7.5	16,700	N
			14	7	17,000	N
			15	7	16,700	N
			16	7.5	15,000	N
			17	6	16,000	Y
			18	6.5	18,350	Y
			19	7	16,650	Y
			20	7.5	18,000	Y
			21	8.5	17,000	N
			22	7	18,200	Y
			26	8	17,500	N
			27	8.5	16,650	N
			28	7.5	18,000	N
			55	8	-	Y
			57	8.5	17,500	Y
			58	8.5	16,500	Y
			59	9	-	Y
			60	9	16,650	N
			61	9	16,650	Y
			62	9.5	16,000	N
			63	9.5	19,000	N
			64	9.5	20,000	N
			65	9.5	17,150	N
			66	9.5	16,000	N
			67	9.5	16,650	N

AVERAGE DONOR VELOCITY OF DETONATION = 17,050 ft/sec (5.20 km/s)

FULLY COUPLED AIR GAP TESTS AT 20°C

CONFINING MEDIUM	PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
5/32" STEEL	EMULSION A	1 1/4	5	8.5	-	-
			6	12	15,750	N
			7	8	-	Y
			8	9	15,700	N
			9	5	18,050	Y
			10	8	14,450	N
			23	8	17,150	Y
			24	7.5	16,950	Y
			25	9	14,700	Y
			29	9.5	18,800	N
			30	9	17,950	Y
			31	8	18,000	Y
			32	9.5	17,350	Y
			35	10	16,450	N
			43	10	18,000	N
			44	10	18,000	N
			68	10	16,900	N
			69	10	17,600	N
			70	10	16,250	N
			71	7.5	-	N
			72	7.5	18,400	N
			73	7	19,100	N
			76	6.5	17,000	Y
			77	6.5	18,600	N
			78	6	16,150	Y
			79	6	19,000	Y
			80	6	16,000	Y
			81	6	19,000	N
			87	8.5	20,000	Y
			88	7	18,000	Y
			89	9.5	18,150	Y
			90	10	18,750	N
			91	6.5	15,850	Y
			92	7	15,500	Y
			93	8.5	-	-
			94	8.5	19,050	N
			95	9	17,000	N
			96	9.5	16,900	Y
			97	6.5	18,200	Y
			98	7	18,650	N
			99	7.5	17,350	Y
			100	9.5	16,000	N
			101	8.5	-	-
			102	8.5	17,500	Y

AVERAGE DONOR VELOCITY OF DETONATION = 17,350 ft/sec (5.30 km/s)

FULLY COUPLED AIR GAP TESTS AT 20°C

CONFINING MEDIUM	PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
1/16" STEEL	EMULSION A	1 1/4	33	8	17,200	Y
			34	8.5	18,000	Y
			82	9	-	N
			83	9	16,500	Y
			84	9	-	N
1/32" STEEL	EMULSION A	1 1/4	49	8	-	N
			51	7.5	-	Y
1/8" ALUMINUM	EMULSION A	1 1/4	45	9	16,400	N
			46	9	16,500	N
			47	9	17,000	N
			48	8.5	19,150	Y
			50	8	17,850	N
			52	7.5	15,400	Y
			53	7.5	17,250	Y
			54	8	18,750	Y
AVERAGE DONOR VELOCITY OF DETONATION = 17,250 ft/sec (5.26 km/s)						
5/32" STEEL	EMULSION A	1 3/4	38	14	16,470	N
			39	12	17,700	Y
			40	13	15,450	N
			41	13	19,900	Y
			42	14	-	N
			74	14	19,000	N
			75	14	20,000	Y
AVERAGE DONOR VELOCITY OF DETONATION = 18,100 ft/sec (5.51 km/s)						

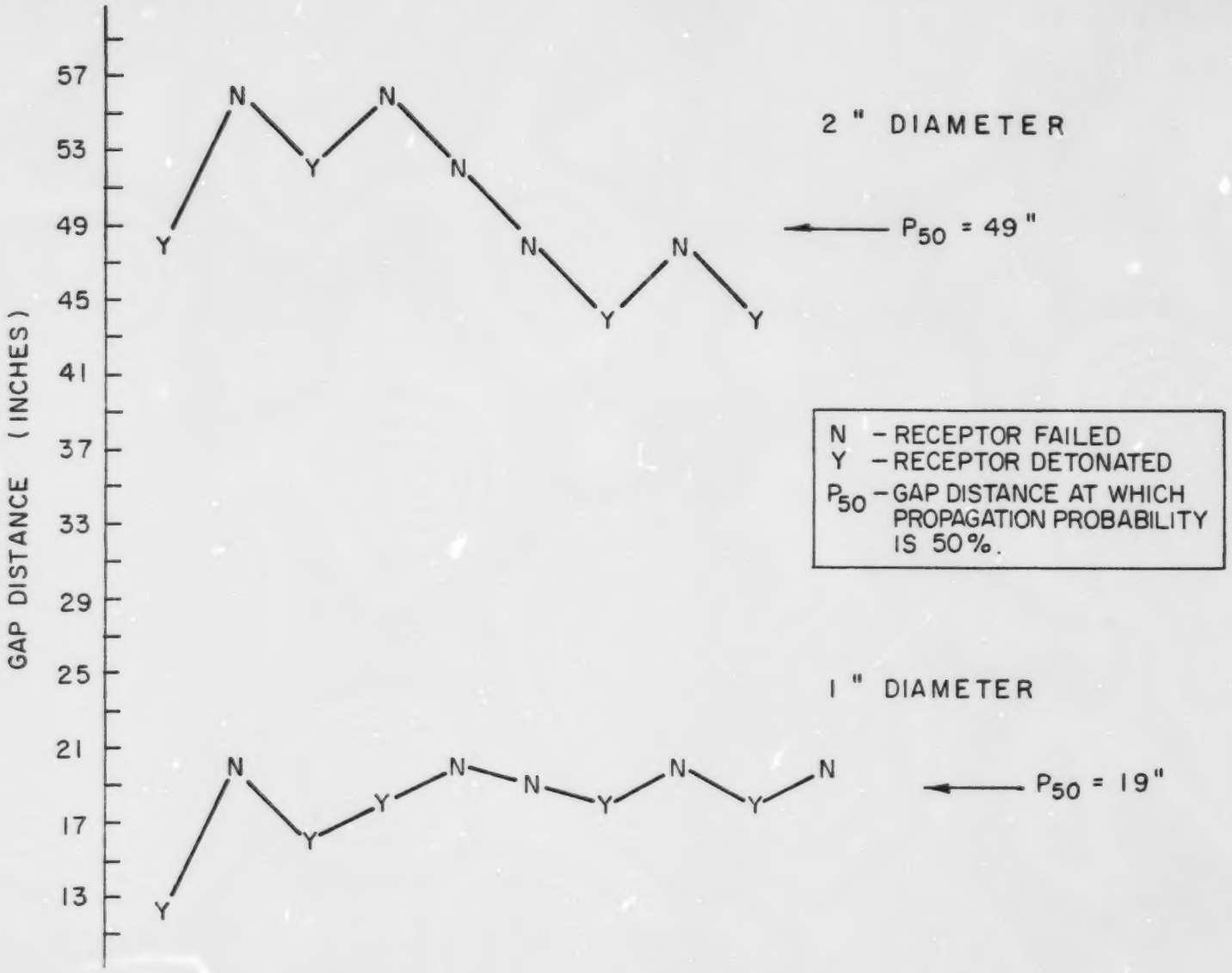
APPENDIX D

COMPARISON OF AVERAGE VELOCITY OF DETONATION FOR GLASS MICROBUBBLE SENSITIZED EMULSION WHEN CONFINED BY STEEL PIPE AND GRANITE.

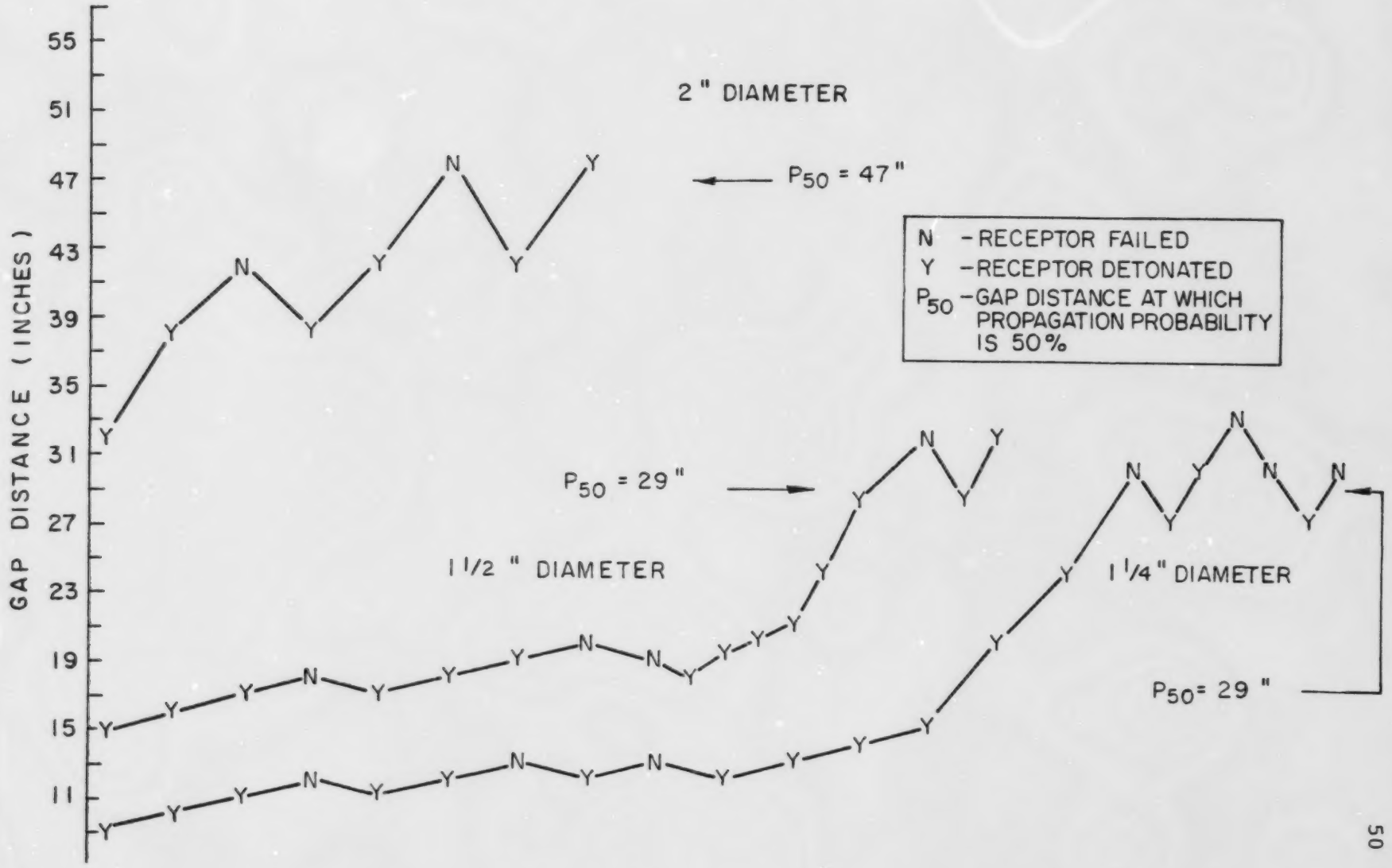
CONFINING MEDIUM	AVERAGE VELOCITY OF DETONATION FOR A 1 1/4" DIAMETER EMULSION A CHARGE	
GRANITE	17,050 ft/sec	(5.20 km/s)
5/32" STEEL	17,350 ft/sec	(5.30 km/s)
1/16" STEEL	17,250 ft/sec	(5.26 km/s)
1/8" ALUMINUM	17,300 ft/sec	(5.25 km/s)

APPENDIX E

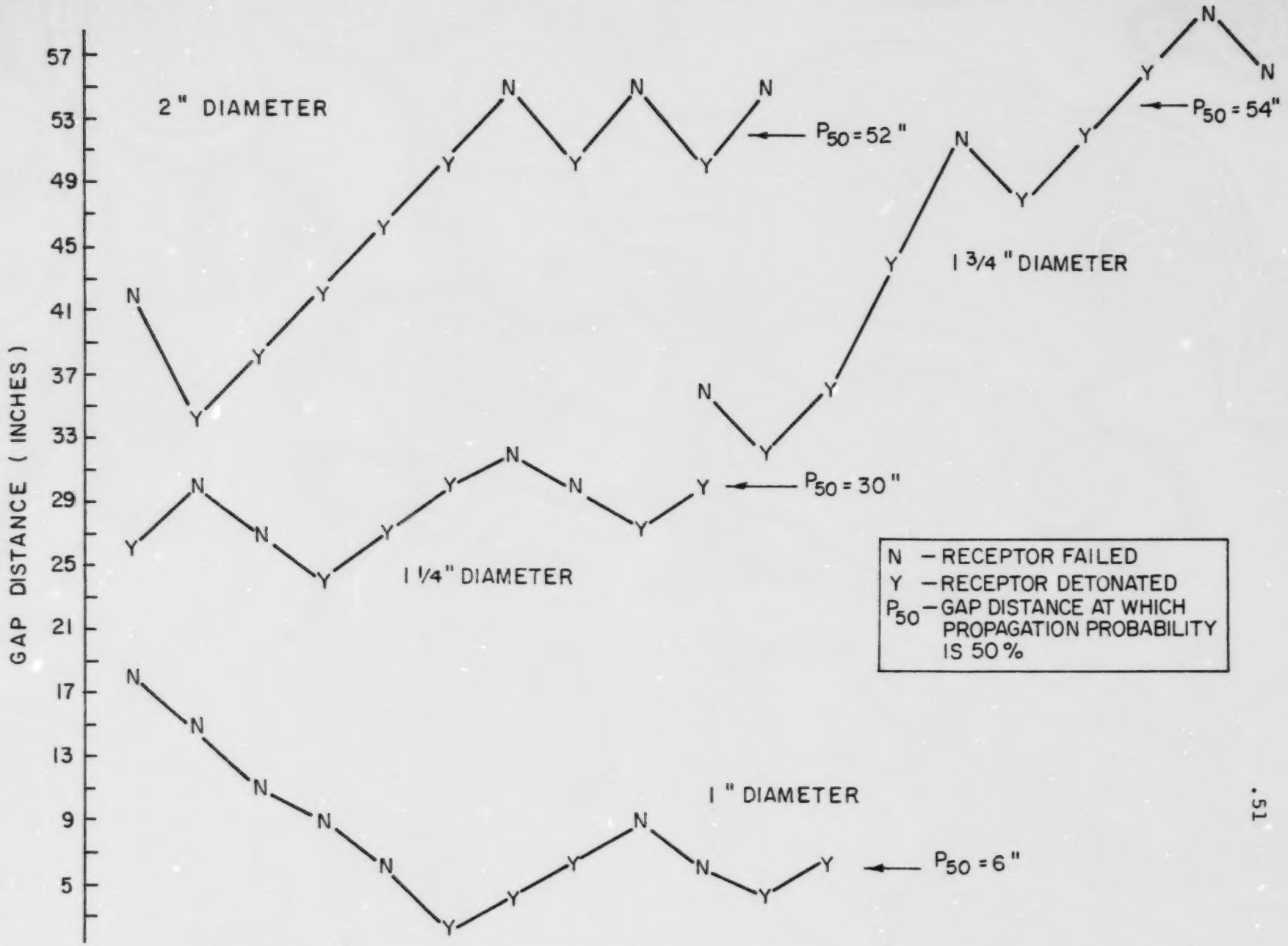
EXPERIMENTAL RESULTS FOR FULLY COUPLED AIR GAP TESTS AT 20°C IN GRANITE.

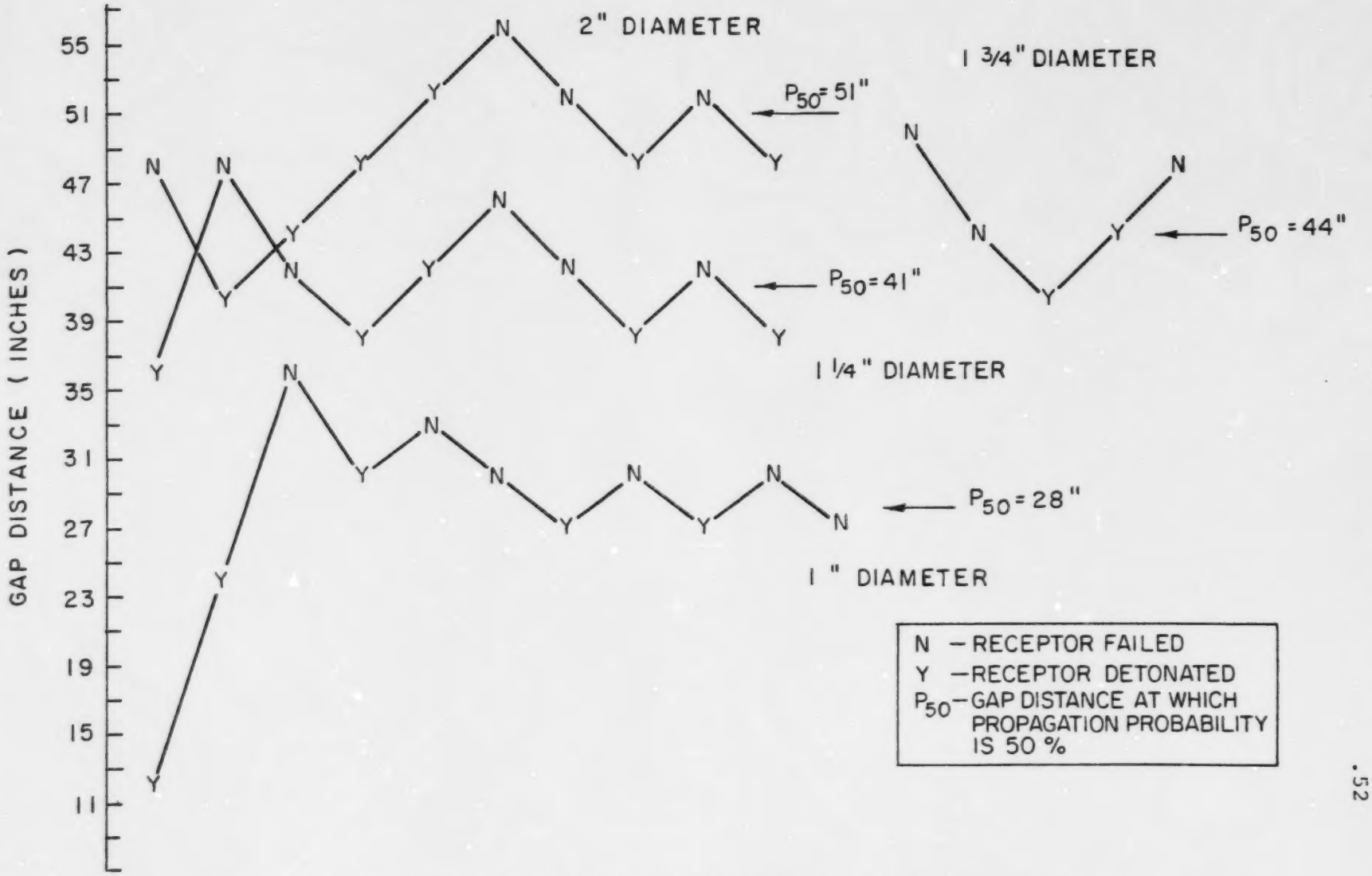


FULLY COUPLED AIR GAP RESULTS AT 20 °C FOR SLURRY A

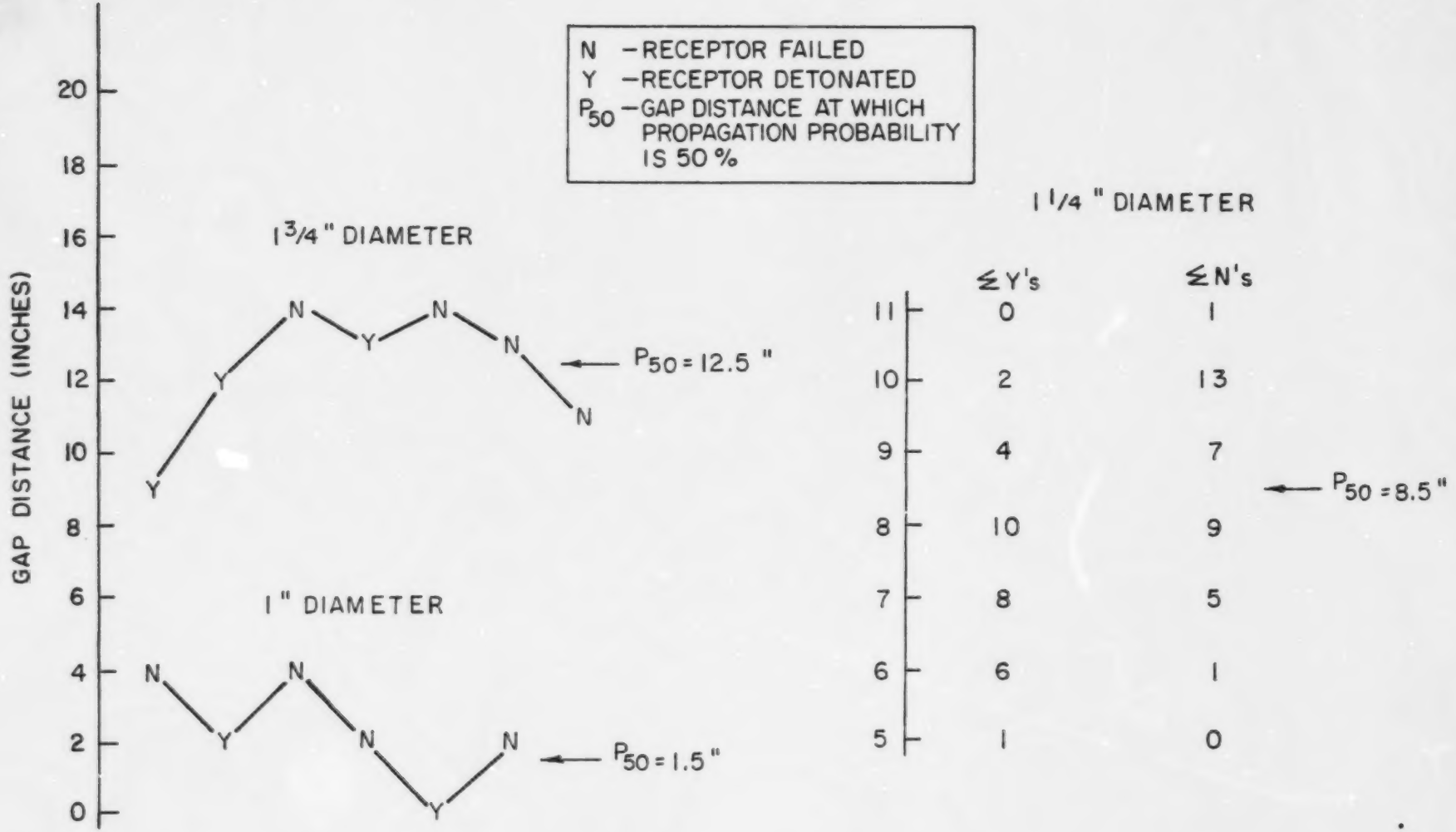


FULLY COUPLED AIR GAP RESULTS AT 20° C FOR SLURRY B.

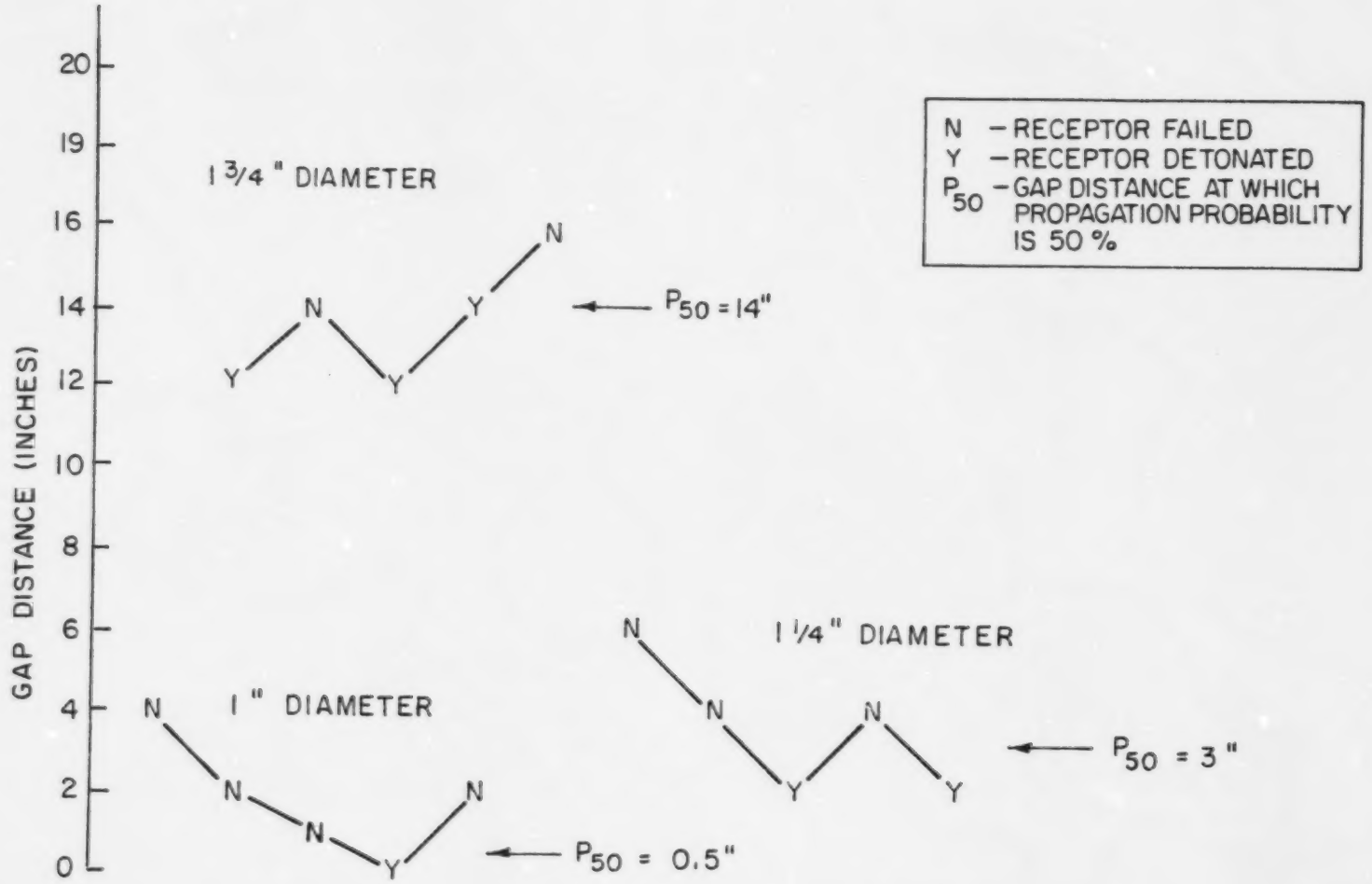

GAP DISTANCE (INCHES)
57
53
49
45
41
37
33
29
25
21
17
13
9
5
2" DIAMETER
N
Y
N
Y
N
Y



FULLY COUPLED AIR GAP RESULTS AT 20° C FOR WATER GEL B.



FULLY COUPLED AIR GAP RESULTS AT 20°C FOR EMULSION A.



FULLY COUPLED AIR GAP RESULTS AT 20°C FOR EMULSION B.

FULLY COUPLED AIR GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY A	1	190	12	11,100	Y
		191	20	-	N
		192	16	9,650	Y
		193	18	10,200	Y
		194	20	12,200	N
		195	19	11,100	N
		196	18	10,850	Y
		197	20	-	N
		198	18	12,800	Y
		199	20	-	N
	AVERAGE DONOR VELOCITY OF DETONATION =			11,150 ft/sec (3.39 km/s)	
	2	300	48	13,750	Y
		301	56	13,150	N
		302	52	13,750	Y
		303	56	14,600	N
		304	52	15,600	N
		305	48	15,000	N
		306	44	13,750	Y
		308	48	13,450	N
	AVERAGE DONOR VELOCITY OF DETONATION =			14,150 ft/sec (4.31 km/s)	
SLURRY B	1 1/4	131	9	10,400	Y
		132	10	11,000	Y
		133	11	12,350	Y
		134	12	12,300	N
		135	11	11,500	Y
		136	12	11,500	Y
		137	13	11,000	N
		149	12	12,500	Y
		150	13	11,500	N
		151	12	11,250	Y
		168	13	12,200	Y
		169	14	12,000	Y
		170	15	12,400	Y
		185	20	-	Y
		186	24	13,000	Y
		188	30	10,950	N
		189	27	11,650	Y
		200	30	10,700	Y
		201	34	12,750	N
		202	30	11,800	N
		203	27	11,100	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			11,700 ft/sec (3.56 km/s)	

FULLY COUPLED AIR GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY B	1 1/2	138	15	14,000	Y
		139	16	13,800	Y
		141	17	13,150	Y
		142	18	13,350	N
		143	17	14,850	Y
		144	18	14,000	Y
		145	19	14,350	Y
		161	20	14,300	N
		162	19	-	N
		173	18	13,650	Y
		174	19	14,500	Y
		175	20	15,000	Y
		176	21	13,900	Y
		325	24	-	Y
		326	28	14,400	Y
		327	32	14,000	N
		328	28	14,400	Y
		329	32	12,500	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			14,000 ft/sec (4.27 km/s)	
	2	130	12	18,000	Y
		182	32	14,400	Y
		183	38	13,750	Y
		184	42	14,200	N
		295	38	12,000	Y
		296	42	12,500	Y
		297	48	14,400	N
		298	42	12,500	Y
		299	48	12,500	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			13,800 ft/sec (4.21 km/s)	
WATER GEL A	1	216	18	9,650	N
		217	14	10,000	N
		218	10	10,450	N
		219	8	10,700	N
		221	6	10,250	N
		222	2	10,250	Y
		232	4	10,900	Y
		233	6	11,450	Y
		234	9	10,000	N
		235	6	11,250	N
		257	4	12,800	Y
		258	6	10,800	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			10,700 ft/sec (3.26 km/s)	

FULLY COUPLED AIR GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
WATER GEL A	1 1/4	206	26	15,000	Y
		207	30	11,650	N
		208	27	13,150	N
		209	24	12,600	Y
		210	27	13,900	Y
		211	30	12,750	Y
		212	33	12,700	N
		213	30	13,150	N
		214	27	-	Y
		215	30	11,100	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			12,900 ft/sec (3.93 km/s)	
	1 3/4	180	18	13,650	Y
		181	19	13,100	Y
		284	36	12,000	N
		285	32	14,250	Y
		286	36	15,400	Y
		287	44	16,000	Y
		288	52	-	N
		289	48	12,000	Y
		290	52	11,650	Y
		291	56	13,350	Y
		323	60	-	N
		324	56	-	N
	AVERAGE DONOR VELOCITY OF DETONATION =			13,500 ft/sec (4.11 km/s)	
	2	146	27	15,550	Y
		223	42	13,750	N
		224	34	13,500	Y
		225	38	14,250	Y
		226	42	13,050	Y
		227	46	13,650	Y
		228	50	-	Y
		229	55	13,450	N
		230	50	13,750	Y
		231	55	14,400	N
		293	50	13,150	Y
		294	55	13,150	N
	AVERAGE DONOR VELOCITY OF DETONATION =			13,800 ft/sec (4.20 km/s)	

FULLY COUPLED AIR GAP TESTS AT 20°C

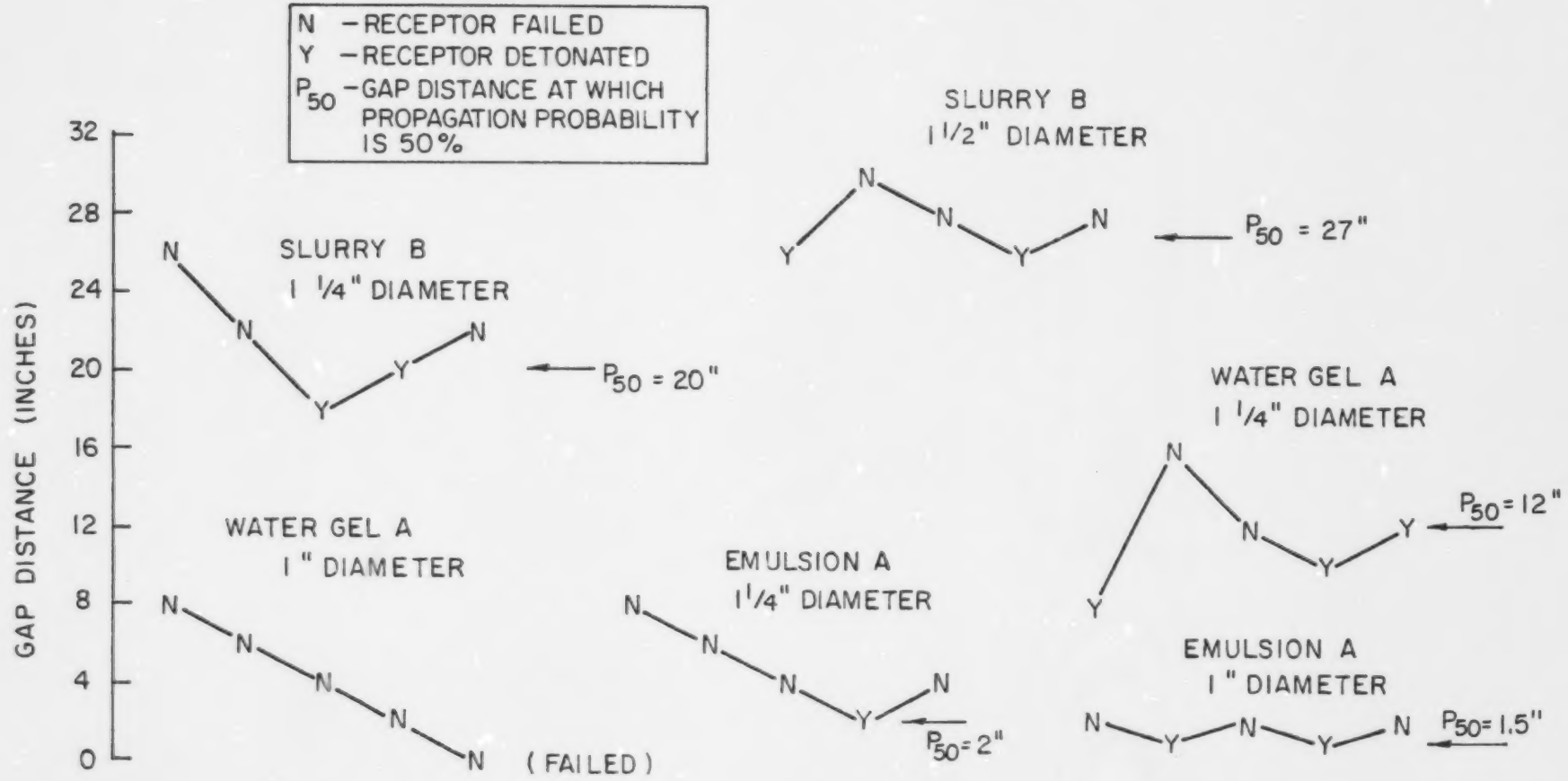
PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
WATER GEL B	1	236	12	12,100	Y
		237	24	11,650	Y
		238	36	14,400	N
		239	30	11,300	Y
		240	33	10,900	N
		241	30	10,000	N
		252	27	11,000	Y
		253	30	11,800	N
		254	27	11,500	Y
		255	30	12,050	N
		256	27	11,350	N
	AVERAGE DONOR VELOCITY OF DETONATION =			11,650 ft/sec (3.55 km/s)	
	1 1/4	274	36	16,650	Y
		275	48	14,550	N
		276	42	13,250	N
		277	38	13,000	Y
		278	42	13,000	Y
		279	46	12,500	N
		280	42	-	N
		281	38	-	Y
		282	42	12,500	N
		283	38	13,250	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			13,600 ft/sec (4.14 km/s)	
	1 3/4	292	50	14,500	N
		319	44	15,600	N
		320	40	12,500	Y
		321	44	13,150	Y
		322	48	-	N
	AVERAGE DONOR VELOCITY OF DETONATION =			13,950 ft/sec (4.25 km/s)	
	2	309	48	12,500	N
		310	40	-	Y
		311	44	14,150	Y
		312	48	-	Y
		313	52	12,100	Y
		314	56	13,550	N
		315	52	13,350	N
		316	48	-	Y
		317	52	12,950	N
		318	48	12,850	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			13,100 ft/sec (3.98 km/s)	

FULLY COUPLED AIR GAP TESTS AT 20°C

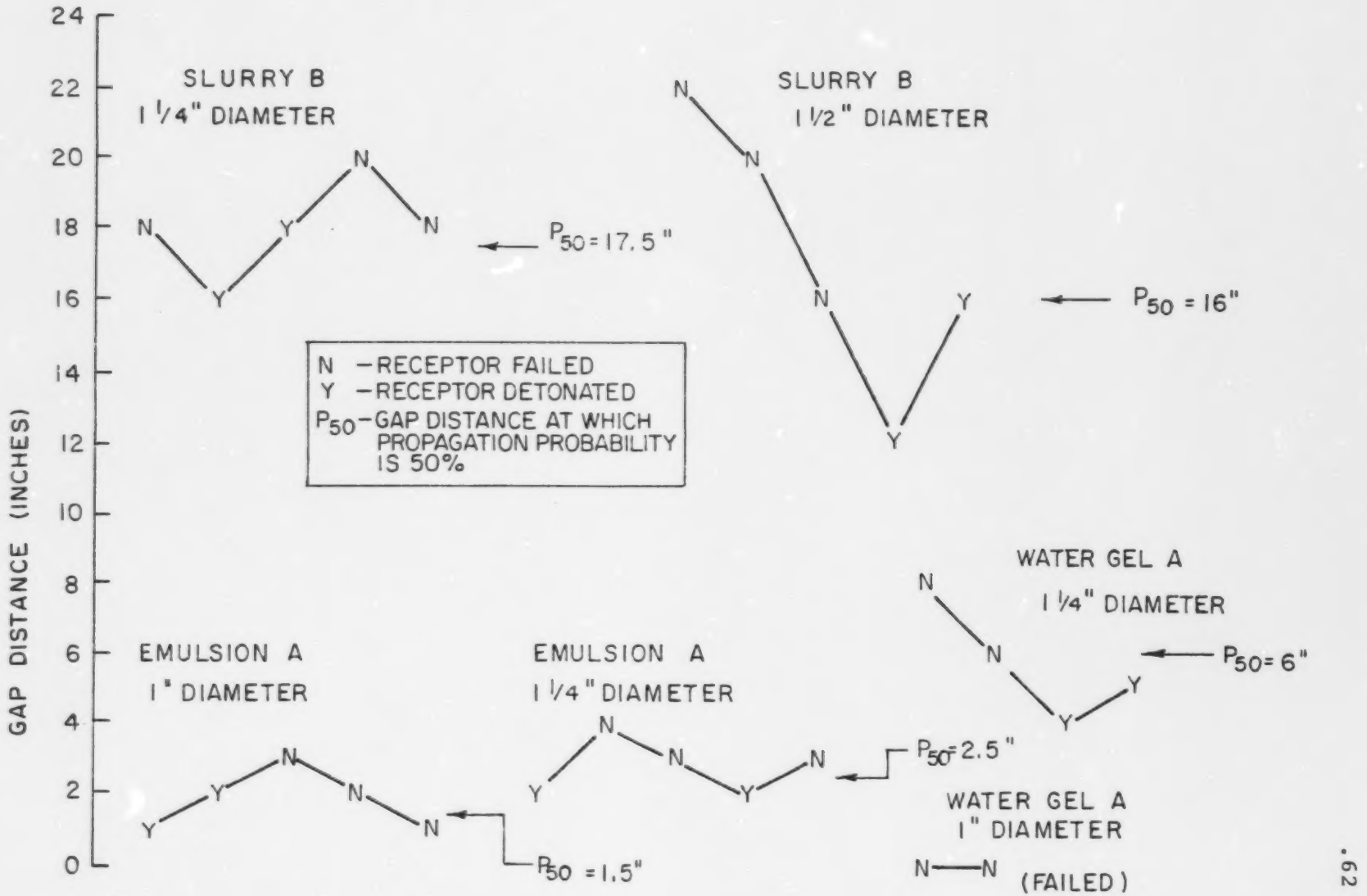
PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
EMULSION A	1	390	4	-	N
		391	2	15,200	Y
		392	4	14,450	N
		393	2	14,450	N
		394	2	13,750	N
	AVERAGE DONOR VELOCITY OF DETONATION =			14,450 ft/sec (4.41 km/s)	
	1 1/4	SEE APPENDIX C - granite confined and 5/32" STEEL confined			
	AVERAGE DONOR VELOCITY OF DETONATION =			17,250 ft/sec (5.25 km/s)	
	1 3/4	36	9	17,000	Y
		37	11	-	N
		127	10	-	Y
		128	6	-	Y
		ALSO IN APPENDIX C - 5/32" STEEL confined			
	AVERAGE DONOR VELOCITY OF DETONATION =			18,100 ft/sec (5.51 km/s)	
EMULSION B	1	395	4	15,000	N
		396	2	15,500	N
		397	2	14,250	N
		398	4	15,000	N
		399	2	15,500	N
		405	0	14,300	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			14,950 ft/sec (4.55 km/s)	
	1 1/4	400	6	15,350	N
		401	4	16,050	N
		402	2	15,000	Y
		403	4	16,750	N
		404	2	15,200	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			15,700 ft/sec (4.79 km/s)	
	1 3/4	471	12	17,650	Y
		472	12	16,950	Y
		473	14	-	N
		474	14	-	Y
		475	16	-	N
	AVERAGE DONOR VELOCITY OF DETONATION =			17,300 ft/sec (5.27 km/s)	

APPENDIX F

EXPERIMENTAL RESULTS FOR FULLY COUPLED AIR GAP TESTS AT +5°C AND -5°C IN GRANITE.



FULLY COUPLED AIR GAP RESULTS AT 5° C.



FULLY COUPLED AIR GAP RESULTS AT -5°C.

FULLY COUPLED AIR GAP TESTS AT +5°C

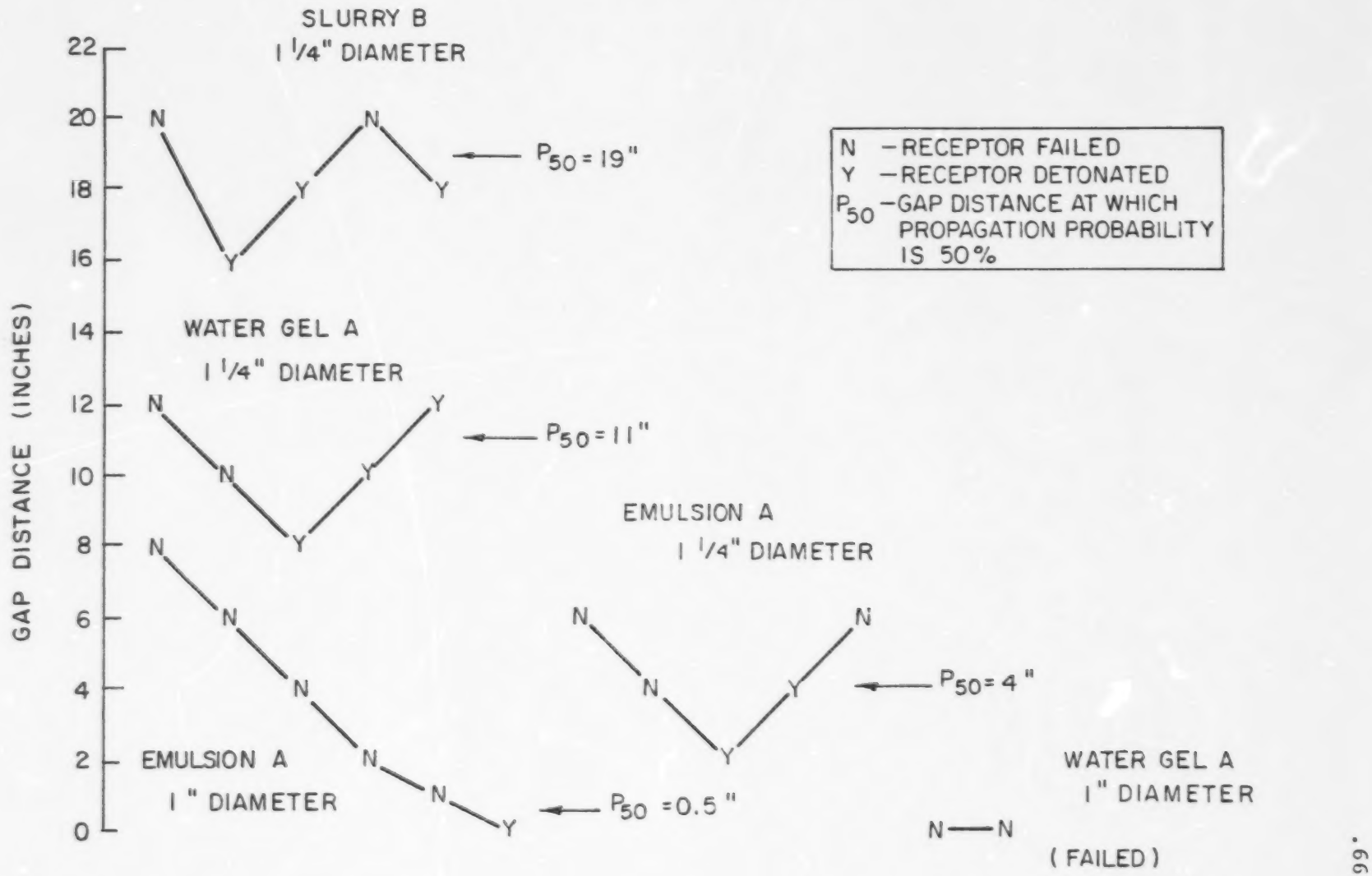
PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY B	1 1/4	423	26	10,000	N
		424	22	9,550	N
		425	18	9,250	Y
		426	20	10,650	Y
		427	22	10,500	N
	AVERAGE DONOR VELOCITY OF DETONATION =			10,000 ft/sec (3.05 km/s)	
	1 1/2	428	26	14,800	Y
		429	30	13,350	N
		430	28	13,350	N
		431	26	-	Y
		432	28	14,800	N
	AVERAGE DONOR VELOCITY OF DETONATION =			14,100 ft/sec (4.30 km/s)	
WATER GEL A	1	413	8	DECAYING	N
		414	6		N
		415	4	(SUB-CRITICAL	N
		416	2	DIAMETER)	N
		417	0		N
	1 1/4	418	8	12,000	Y
		419	16	-	N
		420	12	10,500	N
		421	10	10,850	Y
		422	12	11,500	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			11,200 ft/sec (3.41 km/s)	
EMULSION A	1	433	2	15,150	N
		434	1	16,650	Y
		435	2	10,000	N
		436	1	15,000	Y
		437	2	16,450	N
	AVERAGE DONOR VELOCITY OF DETONATION =			16,650 ft/sec (5.07 km/s)	
	1 1/4	438	8	16,700	N
		439	6	15,600	N
		440	4	14,300	N
		441	2	15,500	Y
		442	4	16,450	N
	AVERAGE DONOR VELOCITY OF DETONATION =			15,700 ft/sec (4.79 km/s)	

FULLY COUPLED AIR GAP TESTS AT -5°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY B	1 1/4	450	18	10,500	N
		451	16	13,350	Y
		452	22	13,500	N
		456	18	10,700	Y
		457	20	10,950	N
		458	18	9,350	N
	AVERAGE DONOR VELOCITY OF DETONATION =			11,400 ft/sec (3.47 km/s)	
	1 1/2	462	20	13,700	N
		463	16	11,000	N
		464	12	15,550	Y
		465	16	-	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			13,400 ft/sec (4.08 km/s)	
WATER GEL A	1	443	0	DECAYING (SUB-CRITICAL DIAMETER)	N
		453	0		N
	1 1/4	447	8	10,450	N
		449	6	11,750	N
		454	4	11,250	Y
		455	5	10,850	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			11,100 ft/sec (3.38 km/s)	
EMULSION A	1	444	1	18,500	Y
		445	2	13,250	Y
		466	3	17,000	N
		467	2	14,300	N
		468	1	15,000	N
	AVERAGE DONOR VELOCITY OF DETONATION =			15,600 ft/sec (4.75 km/s)	
	1 1/4	446	2	16,450	Y
		448	4	18,000	N
		459	3	15,750	N
		460	2	17,000	Y
		461	3	16,500	N
	AVERAGE DONOR VELOCITY OF DETONATION =			16,750 ft/sec (5.11 km/s)	

APPENDIX G

EXPERIMENTAL RESULTS FOR AIR GAP TESTS
AT 20°C USING DECOUPLED DONOR
AND ACCEPTOR CHARGES IN 1 3/4" DIAMETER
HOLES IN GRANITE.



DECOUPLED AIR GAP RESULTS AT 20° C. SHOT IN 1¾" DIAMETER HOLES.

DECOUPLED AIR GAP TESTS AT 20°C

PRODUCT	CHARGE DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY B	1 1/4	365	0	11,100	continuous
		383	20	10,000	N
		384	16	11,000	Y
		385	18	10,400	Y
		386	20	10,650	N
		387	18	10,850	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			10,650 ft/sec	(3.25 km/s)
WATER GEL A	1	366	0	-	failed
		367	0	-	failed
	1 1/4	363	0	11,650	continuous
		364	0	11,100	continuous
		378	12	11,650	N
		379	10	13,350	N
		380	8	12,000	Y
		381	10	11,650	Y
		382	12	11,350	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			11,800 ft/sec	(3.60 km/s)
EMULSION A	1	362	0	15,550	continuous
		368	8	14,500	N
		369	6	14,500	N
		370	4	14,500	N
		371	2	14,650	N
		372	1	16,950	N
		388	0	15,350	continuous
	AVERAGE DONOR VELOCITY OF DETONATION =			15,150 ft/sec	(4.62 km/s)
	1 1/4	360	0	17,350	continuous
		361	0	17,350	continuous
		373	6	18,000	N
		374	4	15,900	N
		375	2	16,650	Y
		376	4	16,000	Y
		377	6	16,650	N
	AVERAGE DONOR VELOCITY OF DETONATION =			16,850 ft/sec	(5.14 km/s)

APPENDIX H

"CHANNEL EFFECT" EVALUATION USING

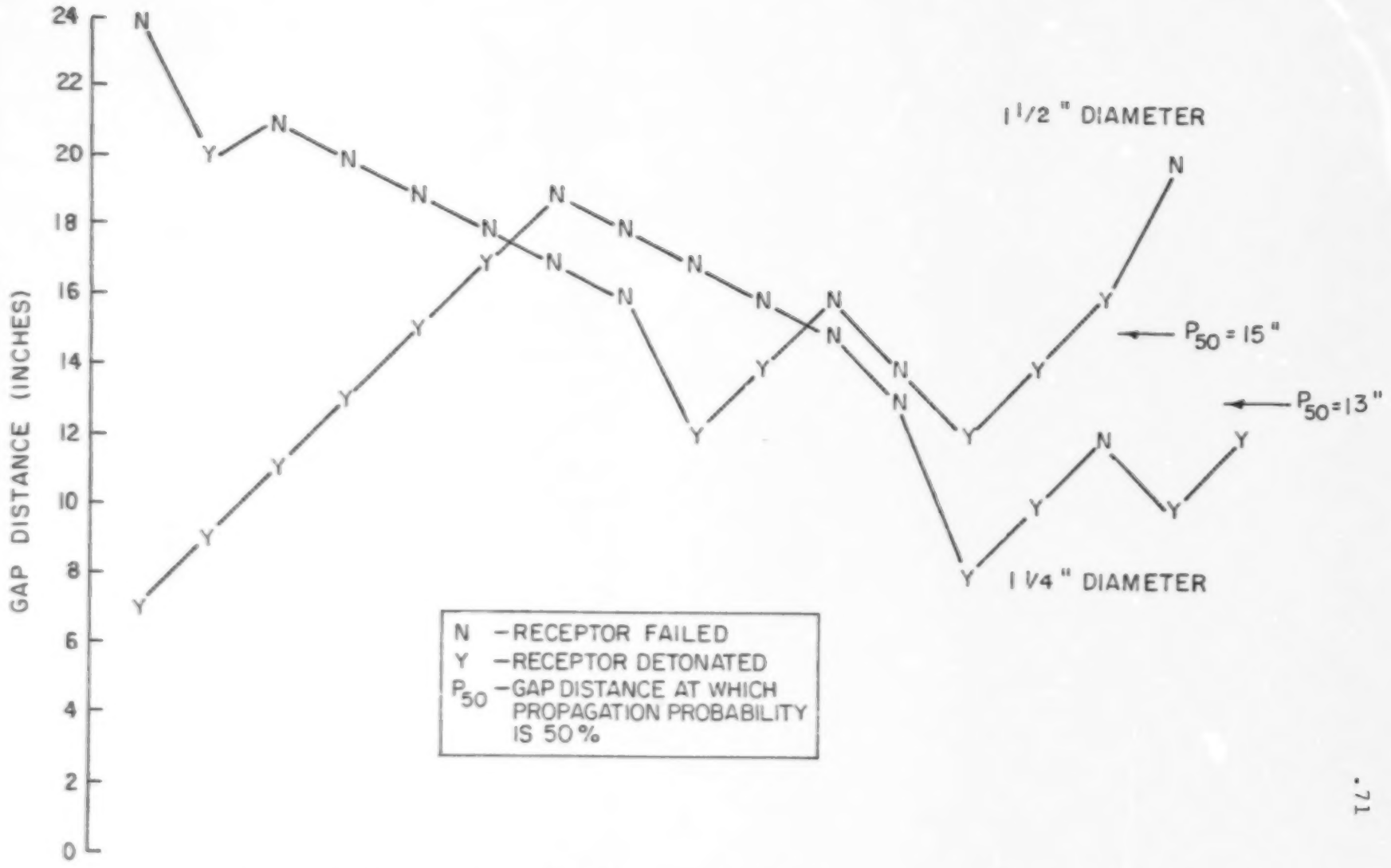
4' LONG DECOUPLED CHARGES

IN 1 3/4" DIAMETER HOLES IN GRANITE.

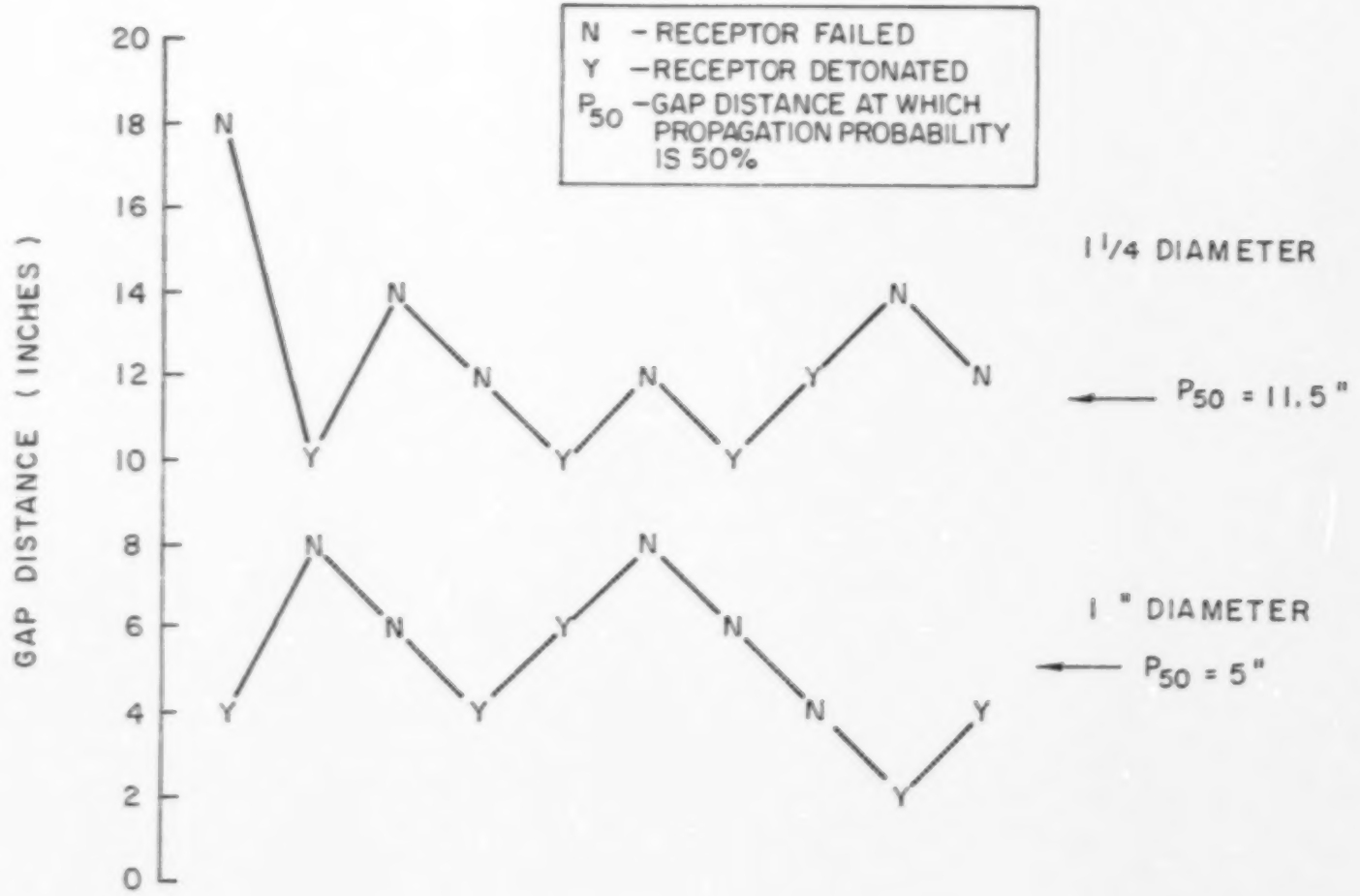
PRODUCT	CHARGE DIAMETER (inches)	DISTANCE ALONG CHARGE (feet)		VELOCITY OF DETONATION
SLURRY B	1 1/4	#365	1	10,800 ft/sec (3.3 km/s)
			2	10,800 ft/sec (3.3 km/s)
			3	10,800 ft/sec (3.3 km/s)
			4	10,800 ft/sec (3.3 km/s)
WATER GEL A	1	#366	1	10,500 ft/sec (3.2 km/s)
			2	9,500 ft/sec (2.9 km/s)
			3	2,950 ft/sec (0.9 km/s)
			4	0
		#367	1	10,500 ft/sec (3.2 km/s)
			2	6,550 ft/sec (2.0 km/s)
			3	0
			4	0
		AVERAGE	1	10,500 ft/sec (3.2 km/s)
			2	8,050 ft/sec (2.5 km/s)
			3	1,475 ft/sec (0.5 km/s)
			4	0
	1 1/4	#363	1	11,800 ft/sec (3.6 km/s)
			2	11,800 ft/sec (3.6 km/s)
			3	11,800 ft/sec (3.6 km/s)
			4	11,800 ft/sec (3.6 km/s)
EMULSION A	1	#362	1	15,400 ft/sec (4.7 km/s)
			2	15,400 ft/sec (4.7 km/s)
			3	15,400 ft/sec (4.7 km/s)
			4	15,400 ft/sec (4.7 km/s)
	1 1/4	#361	1	17,400 ft/sec (5.3 km/s)
			2	17,400 ft/sec (5.3 km/s)
			3	17,400 ft/sec (5.3 km/s)
			4	17,400 ft/sec (5.3 km/s)

APPENDIX I

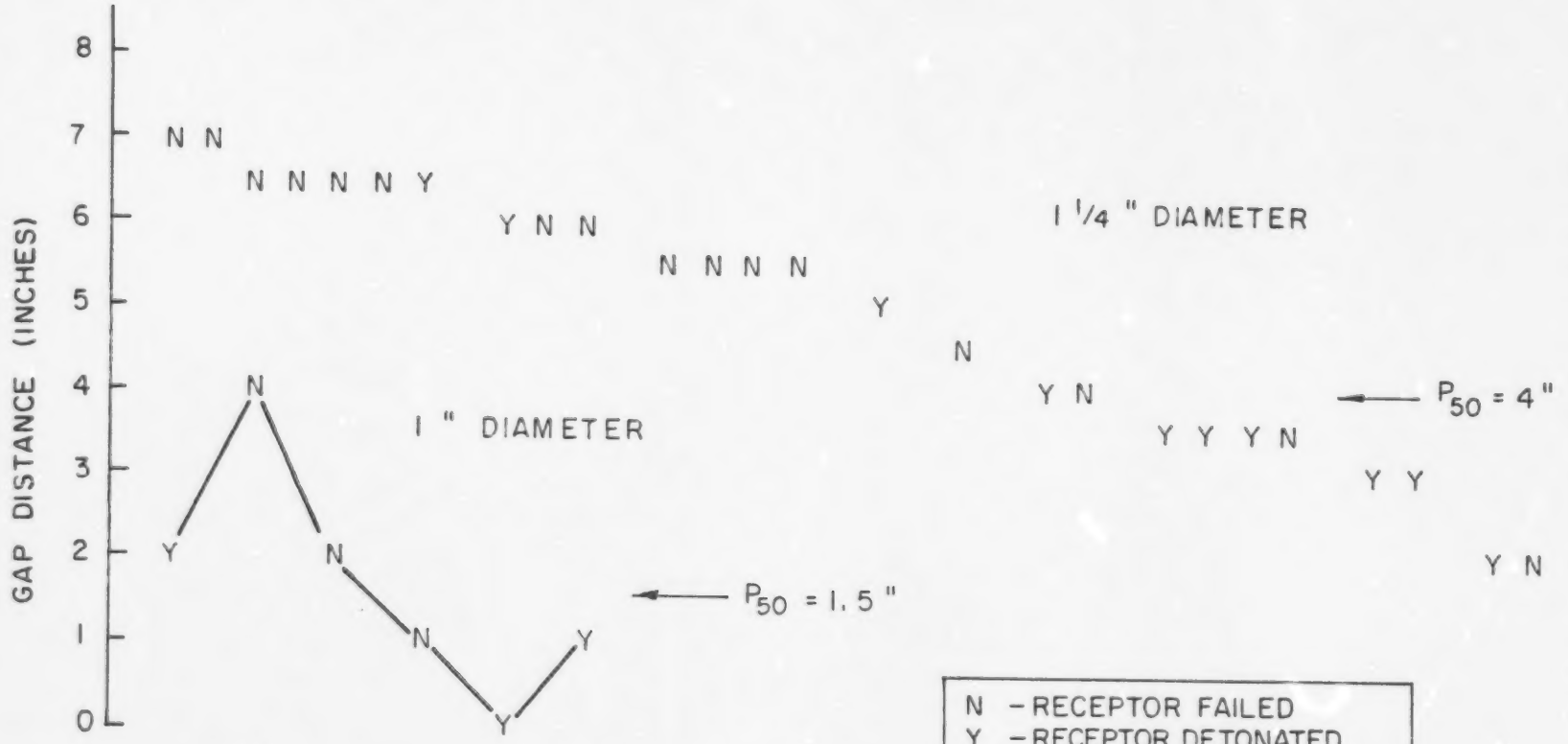
EXPERIMENTAL RESULTS FOR FULLY COUPLED SAND GAP TESTS AT 20°C.



FULLY COUPLED SAND GAP RESULTS AT 20°C FOR SLURRY B.



FULLY COUPLED SAND GAP RESULTS AT 20° C. FOR WATER GEL A.



FULLY COUPLED SAND GAP RESULTS AT 20° C FOR EMULSION A.

FULLY COUPLED SAND GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY B	1 1/4	147	7	13,350	Y
		148	9	15,000	Y
		152	11	13,350	Y
		152	13	11,350	Y
		154	15	11,000	Y
		155	17	10,800	Y
		156	19	12,000	N
		157	18	12,150	N
		158	17	12,800	N
		159	16	13,350	N
		160	15	12,100	N
		171	15	12,650	N
		172	13	12,350	N
		205	8	10,450	Y
		278	10	10,000	Y
		279	12	-	N
		280	12	10,600	N
		281	10	12,500	Y
		282	12	10,000	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			12,000 ft/sec (3.65 km/s)	
	1 1/2	163	24	-	N
		164	20	14,450	Y
		165	21	14,450	N
		166	20	15,000	N
		177	19	12,500	N
		178	18	14,300	N
		179	17	12,500	N
		269	16	13,350	N
		270	12	16,000	Y
		271	14	-	Y
		272	16	14,150	N
		273	14	14,450	N
		275	12	11,250	Y
		276	14	12,000	Y
		277A	16	13,000	Y
		277B	20	15,550	N
	AVERAGE DONOR VELOCITY OF DETONATION =			13,650 ft/sec (4.16 km/s)	

FULLY COUPLED SAND GAP TESTS AT 20°C

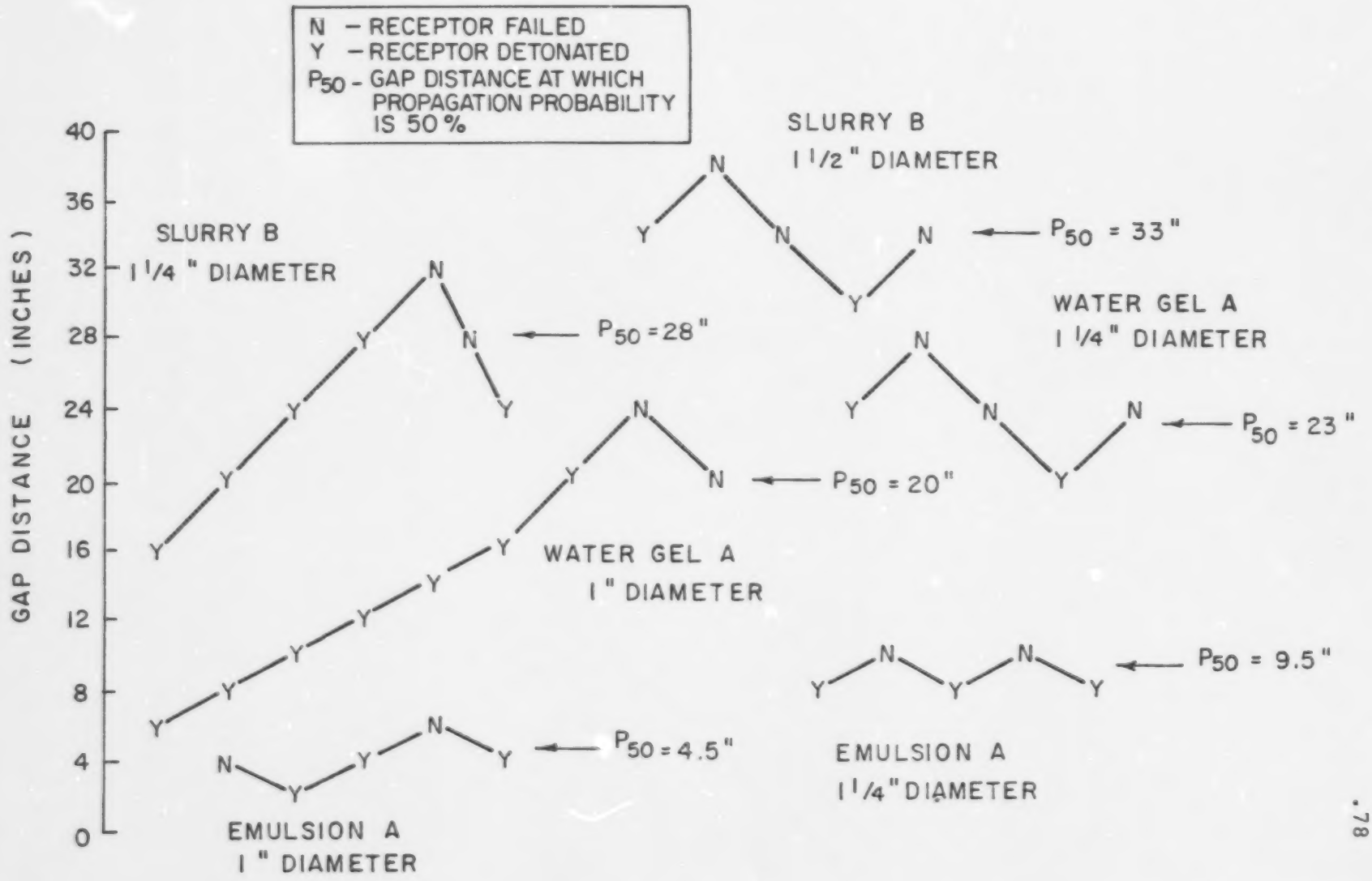
PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
WATER GEL A	1	242	4	10,550	Y
		243	8	10,000	N
		244	6	10,450	N
		245	4	10,000	Y
		246	6	10,200	Y
		247	8	10,450	N
		248	6	10,500	N
		249	4	10,900	N
		250	2	10,650	Y
		251	4	10,900	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			10,500 ft/sec (3.20 km/s)	
	1 1/4	259	18	12,750	N
		260	10	11,050	Y
		261	14	13,350	N
		262	12	12,000	N
		263	10	12,000	Y
		264	12	12,050	N
		265	10	12,150	Y
		266	12	12,500	Y
		267	14	12,500	N
		268	12	11,850	N
	AVERAGE DONOR VELOCITY OF DETONATION =			12,250 ft/sec (3.73 km/s)	
EMULSION A	1	406	2	15,350	Y
		407	4	16,800	N
		408	2	16,450	N
		409	1	16,350	N
		410	1	15,750	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			16,100 ft/sec (4.91 km/s)	
	1 1/4	85	4	17,350	Y
		86	6	18,450	Y
		103	7	15,850	N
		104	6.5	21,350	N
		105	6.5	17,150	N
		106	6.5	17,000	N
		107	6.5	17,750	N
		108	6	17,500	Y
		109	6	18,500	N
		110	6	17,150	N

FULLY COUPLED SAND GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
EMULSION A	1 1/4 (cont.)	111	5.5	18,550	N
		112	5.5	17,400	N
		113	5.5	21,050	N
		114	4.5	18,200	N
		115	5.5	18,000	N
		116	5	-	Y
		117	4	18,350	N
		118	5	17,400	Y
		119	3.5	18,450	Y
		120	3.5	18,350	Y
		121	3.5	18,400	N
		122	3.5	17,700	Y
		123	3	17,700	Y
		124	3	17,850	Y
		125	3	18,900	Y
		126	3	17,700	N
	AVERAGE DONOR VELOCITY OF DETONATION =			18,100 ft/sec (5.50 km/s)	

APPENDIX J

EXPERIMENTAL RESULTS FOR FULLY COUPLED WATER GAP TESTS AT 20°C IN GRANITE.



FULLY COUPLED WATER GAP RESULTS AT 20° C.

FULLY COUPLED WATER GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
SLURRY B	1 1/4	350	16	11,550	Y
		351	20	11,950	Y
		352	24	11,450	Y
		353	28	11,800	Y
		354	32	11,500	N
		476	28	-	N
		477	24	-	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			11,650 ft/sec (3.55 km/s)	
	1 1/2	355	34	14,000	Y
		356	38	14,000	N
		357	34	14,500	N
		358	30	13,500	Y
		359	34	-	N
	AVERAGE DONOR VELOCITY OF DETONATION =			14,000 ft/sec (4.27 km/s)	
WATER GEL A	1	335	6	10,000	Y
		336	8	10,000	Y
		337	10	-	Y
		338	12	10,000	Y
		339	14	10,000	Y
		411	16	10,600	Y
		412	20	10,000	Y
		469	24	-	N
		470	20	10,000	N
	AVERAGE DONOR VELOCITY OF DETONATION =			10,100 ft/sec (3.08 km/s)	
	1 1/4	330	24	15,000	Y
		331	28	11,100	N
		332	24	11,550	N
		333	20	11,600	Y
		334	24	12,400	N
	AVERAGE DONOR VELOCITY OF DETONATION =			12,350 ft/sec (3.76 km/s)	

FULLY COUPLED WATER GAP TESTS AT 20°C

PRODUCT	DIAMETER (inches)	SHOT NUMBER	GAP DISTANCE (inches)	DONOR VELOCITY OF DETONATION (ft/sec)	PROPAGATION (YES,Y/NO,N)
EMULSION A	1	345	4	16,100	N
		346	2	14,900	Y
		347	4	14,600	Y
		348	6	-	N
		349	4	15,100	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			15,200 ft/sec (4.63 km/s)	
	1 1/4	340	8	-	Y
		341	10	16,200	N
		342	8	15,550	Y
		343	10	15,250	N
		344	8	19,000	Y
	AVERAGE DONOR VELOCITY OF DETONATION =			16,500 ft/sec (5.03 km/s)	